AD 663902

THE EFFECTS OF BACKGROUND NOISE UPON PERCEIVED NOISINESS

TECHNICAL REPORT

December 1967

by

David C. Nagel
John E. Parnell
Hugh J. Parry

Bolt Beranek and Newman Inc.
15808 Wyandotte Street
Van Nuys, California 91406

D D C

JAN 18 1968

C

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Aircraft Development Service
Washington, D.C. 20590

6l

TECHNICAL REPORT

DS-67-22

Contract No. FA65WA-1180

THE EFFECTS OF BACKGROUND NOISE
UPON PERCEIVED NOISINESS

By

David C. Nagel
John E. Parnell
Hugh J. Parry

ABSTRACT

Cross modality tests, in which subjects matched the apparent intensity of a 100 Hz vibration applied to the fingertip to the noisiness of one-third octave bands of noise with center frequencies of 125 Hz, 1000 Hz and 4000 Hz, have been conducted to measure the effects of background noise upon the judged noisiness of the bands of noise. The tests have indicated that the growth function for noisiness behaves somewhat like a modified power function of the form $\psi = k(I^n - I_0^n)$ where ψ is noisiness, I is the intensity of the stimulus, I_0 is the threshold intensity for the stimulus in a given background noise and k and n are constants which depend upon the frequency of the stimulus noise band. On the basis of the results of the cross modality tests, a calculation scheme has been developed to account for the effects of background noise in the perceived noise level calculation. The calculation procedure reduces, differentially, the sound pressure level of each third octave band of the judged noise by an amount dependent upon the signal-noise-to-background-noise ratio in that frequency band. For signal-noise-to-background-noise ratios of greater than 65 dB, the band correction is equal to zero. However, preliminary calculations have shown that for realistic background spectra and signal-noise-to-background-noise ratios of 40 dB, the effect upon the perceived noise level of a judged noise, as predicted by the calculation scheme, is approximately 3 PNdB.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Concluded)

I. INTRODUCTION

The current generation of calculation procedures concerned
with predicting human response to noise are based exclusively
on judged attributes such as loudness or noisiness. At this
time these procedures provide a useful and simple basis for
the comparison of different noise spectra. The current
investigation, undertaken in fulfillment of Task IV of FAA
Contract FA65WA-1180, has been directed toward study of the
effects of background noise level on the perceived noisiness
of narrow bands of noise. It is evident, from this report,
that minor modifications of the original methods may be required
to account for the effects of background noise.

The following section of this report presents the back-
ground for the experimental tests described in Section III.
Section IV presents the test results, while Section V describes
a calculation procedure to account for the effects of back-
ground noise level on judged noisiness. The final section
summarizes the conclusions of the study.

II. BACKGROUND

Exposure of humans to intrusive environmental sounds, such as aircraft flyovers, etc., generally occurs in an already high, continuous level of background noise. Little, however, is quantitatively known about how this continuous background noise affects the perceived noisiness of such intrusive sounds. It is generally thought and has been suggested by Kryter (1966)* and others, that a high continuous level of background noise will tend to make a more intense intruding noise somewhat more acceptable than if the same noise is heard in a quieter environment. Pearsons (1966), in laboratory tests in which subjects were asked to rate certain sounds by means of various category scales in the presence of moderately high (47 to 80 PNdB) background noise levels, found that as background level increased, the perceived noisiness for the stimuli decreased in most of the categories. However, the variability of Pearsons' data precluded making any procedural changes in the existing perceived noise level calculation for background noise effects. With this in mind, the present study has attempted to provide a clearer picture as to the effect of background noise on the perceived noisiness of certain sounds and thus upon the perceived noise level calculation.

In actual practice with conventional laboratory testing techniques such as paired-comparison testing, it is difficult to isolate the effects of background noise. When subjects judge the relative noisiness of two stimuli, the first of which is a sound in a quiet background situation and the second of which is the same sound immersed in an acoustically noisy background, it is difficult to determine the manner in which subjects are influenced by the background noise in their judgments of the second stimulus. To determine the effects of background noise upon such noisiness or loudness judgments, a particular background noise environment should remain constant throughout any given test session. Thus it becomes necessary to use a more direct or absolute test method, such as a magnitude estimation or category scaling procedure, in which a set of judgments made under one background noise condition may be compared to a similar set made under a different background noise condition.

---

* All references used may be found in alphabetical order in the References section following the conclusion of this report.

Category scaling, as shown by Pearsons' study, has produced results so variable as to be of doubtful use in quantifying any background noise effect. Magnitude estimation has also been shown (Stevens, 1955) to be susceptable to biases tending to disperse the data in a skewed and/or variable fashion. With those points in mind, a cross-modality technique was employed to measure the effect of background noise upon the judgment of noise stimuli.

With this method, the subject was asked to match the apparent intensity of a stimulus in one sense modality with that in a difference sense modality. In the present study, matches were made between the acceptability or noisiness of three one-third octave bands of noise (with center frequencies of 125, 1000, and 4000 Hz) and the apparent intensity of a 100 Hz vibration applied to the fingertip.

In a series of papers, Stevens (1959[a], 1959[b], and 1959[c]) explains and demonstrates cross-modality matching as applied to the problems of testing the assumption that loudness grows as a power function of stimulus intensity and determining the nature of the binaural summation of loudness. The assumption here is that, since an observer can match numbers to loudness (i.e., a magnitude estimation task) and the loudness of one sound to loudness of another (as done to map out equal noisiness contours), he should be able to match the loudness (or noisiness) of a sound to subjective intensities of other modalities, such as vibration on the fingertip. This assumption may be made, according to Stevens, since the observer is doing something basically similar in both types of tasks. Also in using a cross-modality match technique, we may avoid objections that are sometimes raised against the use of numerical estimations as quantitative indices of sensation magnitude.

Stevens (1959[b]) has shown that both loudness and subjective vibration intensity grow as a power function of stimulus intensity. These two relationships may be written:

$$\psi_1 = k_1 \, I_s^{n_1} \qquad (1)$$

$$\psi_2 = k_2 \, A_v^{n_2} \qquad (2)$$

where ψ_1, ψ_2 are loudness (or noisiness) and subjective vibration intensity, respectively

k_1, k_2 are constants for a particular frequency sound or vibration

I_s is sound intensity

A_v is vibration amplitude

n_1, n_2 are exponents which again depend on sound and vibration frequency.

If cross-modality matches are made between the two previously mentioned continua, such that ψ_1 is equated to ψ_2, then the resulting "equal sensation" matching function will have the form:

$$k_1 \, I_s^{n_1} = k_2 \, A_v^{n_2} \tag{3}$$

Or, upon rearranging, we have:

$$\log A_v = \frac{n_1}{n_2} \log I_s + \text{Const.} \tag{4}$$

When plotted on log-log coordinates, this equation determines a straight line with a slope equal to the ratio of the exponents, n_1/n_2. Thus if we know the governing exponent in one continuum and know the value of n_1/n_2, we should be able to predict the value of the governing exponent on the second continuum. Stevens has demonstrated, on a number of continua, that these types of predictions are possible and yield exponents within fairly close limits to those determined by other methods, such as magnitude estimation.

III. TEST PROCEDURE

The actual testing consisted of a preliminary test and a primary test. All testing was performed in a semi-reverberant room having reverberation times of approximately 0.5 seconds over a range of frequencies as measured with a SKL Model 507 decay rate meter. The preliminary test was a magnitude estimation experiment in which each of 15 subjects estimated the apparent intensity of a 100 Hz vibration applied to the fingertip. The task was performed under two conditions of background noise. Each subject estimated the apparent intensity of the vibration in a "quiet" environment and a few days later in an environment in which the background noise spectrum levels approximated those given by an NC50 noise criterion curve. This preliminary test was done both to establish the form of the growth function for vibration, which was to be used later, and to evaluate any possible effect that an acoustically noisy environment might have upon subjective estimates of vibration intensity.

The primary test was a cross-modality experiment in which the same 15 subjects matched the apparent intensity of the 100 Hz vibration to a one-third octave bandwidth noise. The noise was presented with three different center frequencies, 125 Hz, 1000 Hz, and 4000 Hz. Each subject made the required matches in each of four different noise environments. The first was a "quiet" environment while the others had background noise spectrum levels which approximate those given by NC30, NC40 and NC50 noise criterion curves. These spectra were chosen as being representative of real-life contexts in which judgments of complex noise spectra might take place. The objective of the study, then, was to provide a method of evaluating and quantifying the effect of making such judgments in the presence of a continuous background noise with the ultimate aim of developing a procedural change in the perceived noise level calculation scheme to account for such background noise effects.

Instrumentation for these tests is described in Appendix I.

A. Preliminary Tests - Magnitude Estimation for Vibration

Each of 15 subjects (male and female college students ranging in age from 17 to 22 with an average age of 19.6 years) made estimates of the apparent intensity of the 100 Hz vibration which was applied to the tip of their left middle finger in such a manner that the motion of the contactor was perpendicular to the axis of the finger. The actual instructions used are shown in Appendix II.

The subject was first presented with a moderate stimulus, called the standard (25 dB re threshold amplitude), and told to give it a value of 10. He was then presented with stimuli of varying amplitudes from 0 dB to 45 dB in 5 dB increments and asked to give them numerical values proportional to the magnitude of the comparison vibration relative to the standard.

The stimuli were each presented twice in random fashion to counter any possible ordering effects. Four-second samples of the standard and comparison were alternated continuously during the trial. The subject was provided with an answer sheet and was asked to write his estimates in spaces provided on the sheet. In this manner, it was possible to maintain a constant pressure and position with the middle finger of his left hand on the contactor, and minimize any interchange between experimenter and subject. After each trial, the length of which depended upon the subject's response time, the subject signaled the experimenter with a buzzer. The experimenter then switched off the vibration generator and changed the signal level by means of an attenuator. All tests were conducted in a test room isolated from the control equipment and the experimenter. After the end of each session, which lasted about 20 min., the answer sheet was collected and the subject asked to return in several days.

During the first session, the test room was quiet. During the second session, the subject was asked to make his estimates while a background noise was reproduced through a loudspeaker behind his chair. This loudspeaker was located approximately 8 ft directly behind the subject and was directed into the corner of the room to give maximum diffusivity to the sound field. A broadband noise was manipulated with a spectrum shaper to have the one-third octave band sound pressure levels approximate values given by an NC50 noise criterion curve. A plot of the background spectra used may be found in Fig. 1.

B. Primary Test - Cross-Modality Task

Each of the 15 subjects were asked to match the subjective intensity of a 100 Hz vibration applied to the fingertip to the acceptability of a one-third octave band noise which was introduced through the JBL speaker placed so that it faced the subject. The actual instructions used may be found in Appendix · II. As in the magnitude estimation task, the vibration was applied to the middle finger of the left hand of the subject. The subject group was identical to that used in the magnitude estimation investigation. The one-third octave
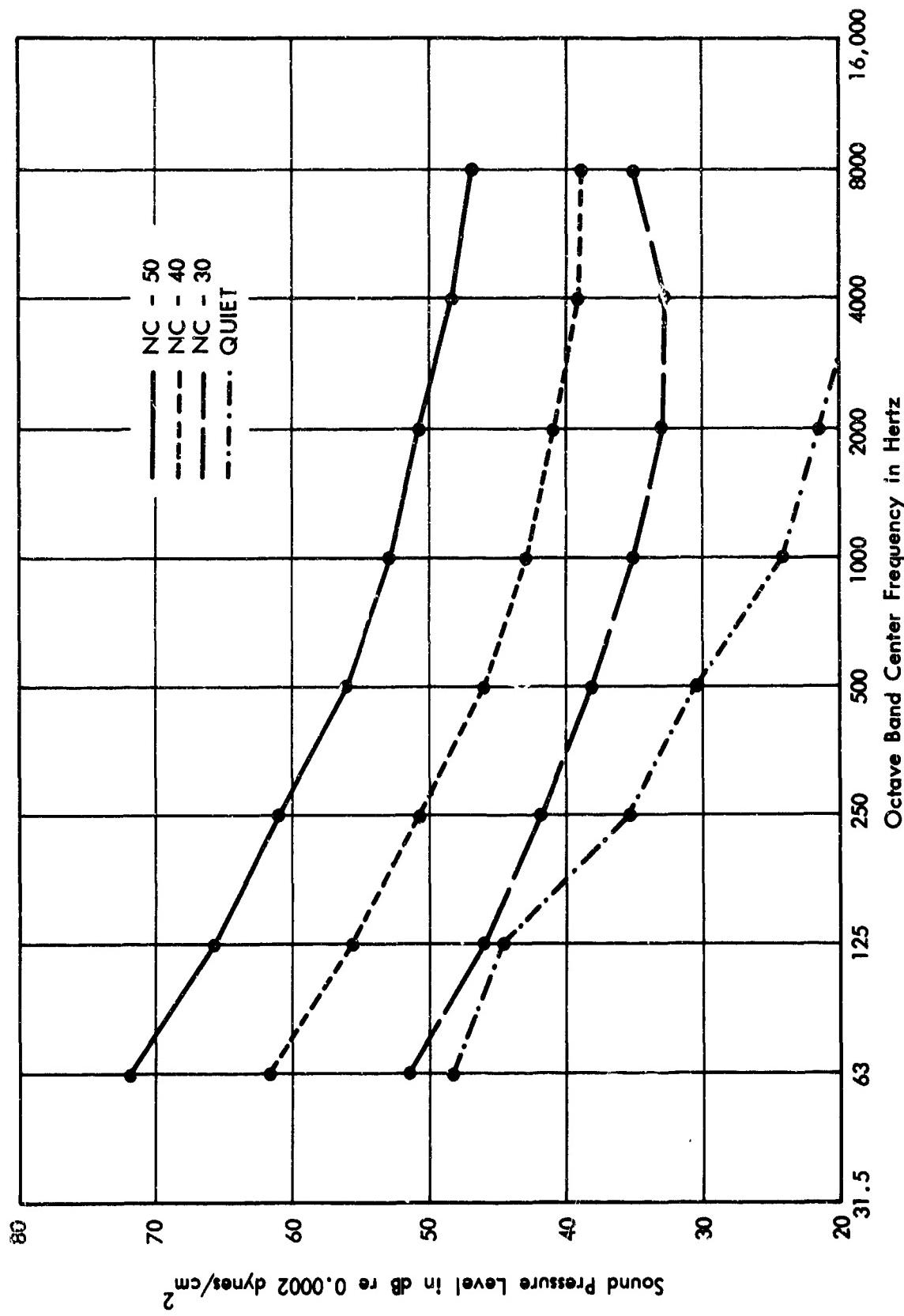
FIGURE 1. MEASURED SPECTRA OF BACKGROUND NOISES USED TO DETERMINE THE GROWTH OF NOISINESS FOR A SIGNAL IN DIFFERENT LEVELS OF NOISE

bands of noise were presented with three different center frequencies, 125 Hz, 1000 Hz, and 4000 Hz. Noise levels were from 44 dB to 100 dB SPL for the 125 Hz noise, 40 dB to 100 dB SPL for the 1000 Hz noise, and 30 dB to 100 dB SPL for the 4000 Hz noise, and were presented in steps of 10 dB. The vibration and noise were presented alternately for four seconds each, in a random ordering. The subject varied the vibration intensity by means of a 100 dB, ten-turn potentiometer situated on a small platform attached to the subject chair. The noise and vibration were presented alternately until the subject had made the required match at which time he signaled the experimenter with a buzzer. The experimenter then monitored the accelerometer voltage with a sound level meter, used as a millivoltmeter, and reset the attenuator and one-third octave band stimulus filter for the next stimulus pair.

This procedure was repeated for all stimulus pairs at which time the subject left the test room and took a 10-min. break. During this period, with the subject absent from the room, one of the three background noises was turned on. The subject then returned and repeated the entire task. The subject was given another rest period and the background noise was changed again, with this sequence being repeated until the test was performed in all four noise environments: quiet, and NC30, NC40, and NC50 shaped background spectra. The order in which the background noises were used was varied from subject to subject, again to counter any ordering effects.

IV. TEST RESULTS AND DISCUSSION

A. Preliminary Test Results

The results of the magnitude estimation tests used to
determine the growth function for vibration in quiet and
noise are shown in Figs. 2 and 3. Over the range of stimuli
tested, from threshold to 45 dB re threshold, the means of
the estimates approximate a power function of vibration
amplitude for both background noise environments. The slope
of the line (i.e., the exponent of the power function drawn
in log-log coordinates) equals a value of 0.86 for the "quiet"
background noise environment and a value of 0.81 for the NC50
background noise environment. This corresponds to an increase
of 7 dB and 7.5 dB, respectively, in stimulus amplitude for
every judged doubling of magnitude. Stevens (1959[b]) reports
a value for the exponent of 0.94 or about 6.5 dB per doubling,
for the same conditions of stimulation as used in the present
investigation. Stevens predicted that further studies would
show the exponent to be close to unity. However, Stevens'
subject group was small (5 subjects as compared to 15 for the
present investigation) and he reported a slightly more re-
stricted range of stimuli (10 dB to 40 dB re approximate
threshold) than was used in this study.

The growth function for vibration appears unaffected by
the addition of a moderately high level noise to the test
environment. The variability of the data are such that the
observed difference between magnitude estimation functions
for quiet and noise may be attributed to chance variations
and subject variability. We may assume, then, that any
observed differences in an equal sensation (cross modality)
function for vibration and noisiness due to varying background
noise environments must result from a change in the growth
function for noisiness and not from any change in the judgments
of vibration.

This scale of subjective vibration magnitude may now be
used, with the results of the cross-modality tests, to pre-
dict the subjective scale of noisiness, and the effect upon
this scale of making noisiness judgments in an increasingly
high ambient noise level environment.
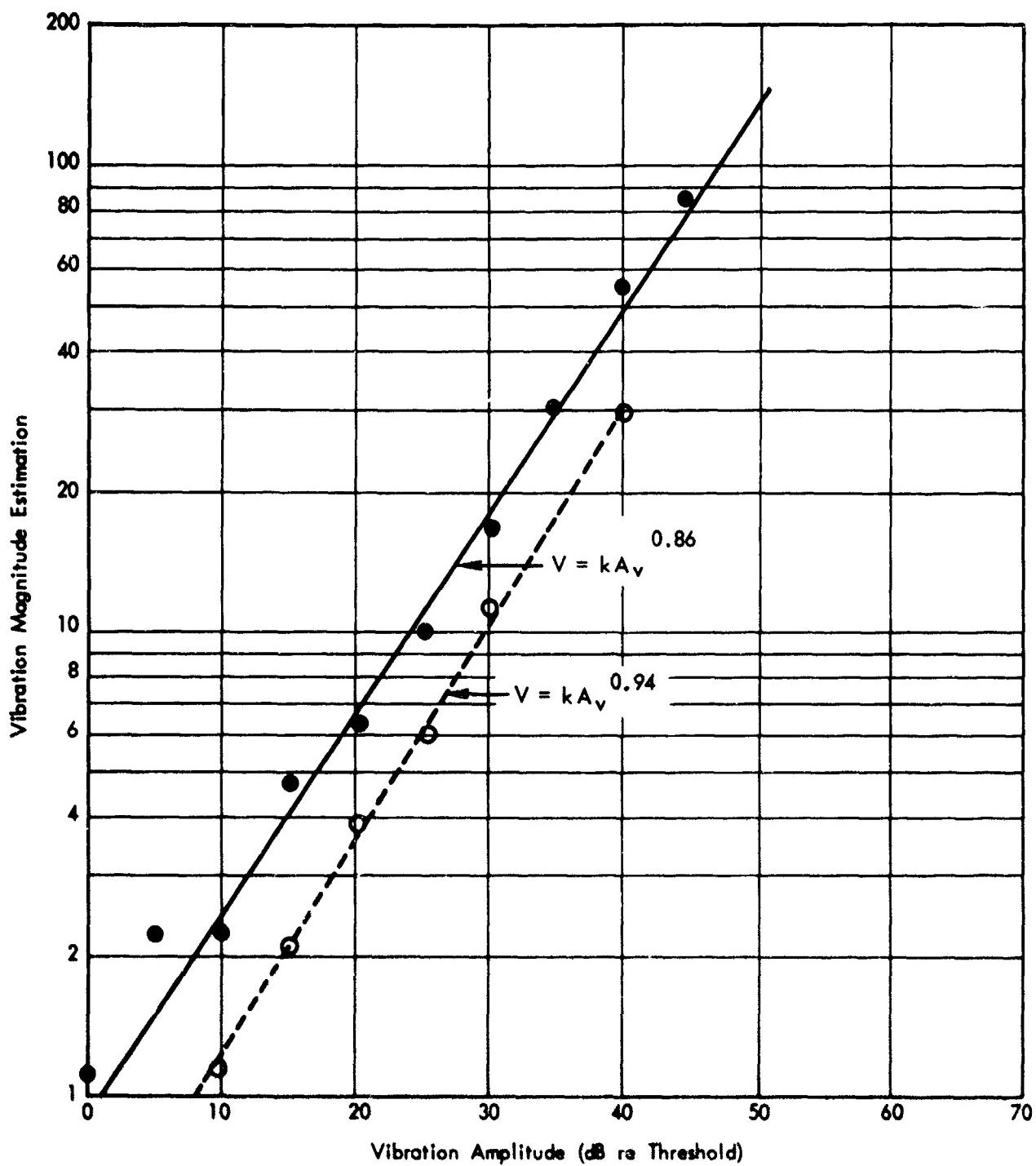
FIGURE 2. MAGNITUDE ESTIMATIONS OF THE APPARENT INTENSITY
OF MECHANICAL VIBRATION ON THE FINGER TIP. CLOSED DATA
POINTS REPRESENT THE MEAN JUDGMENTS OF 15 SUBJECTS.
OPEN DATA POINTS REPRESENT THE DATA OF STEVENS (1959).
QUIET BACKGROUND

-10-
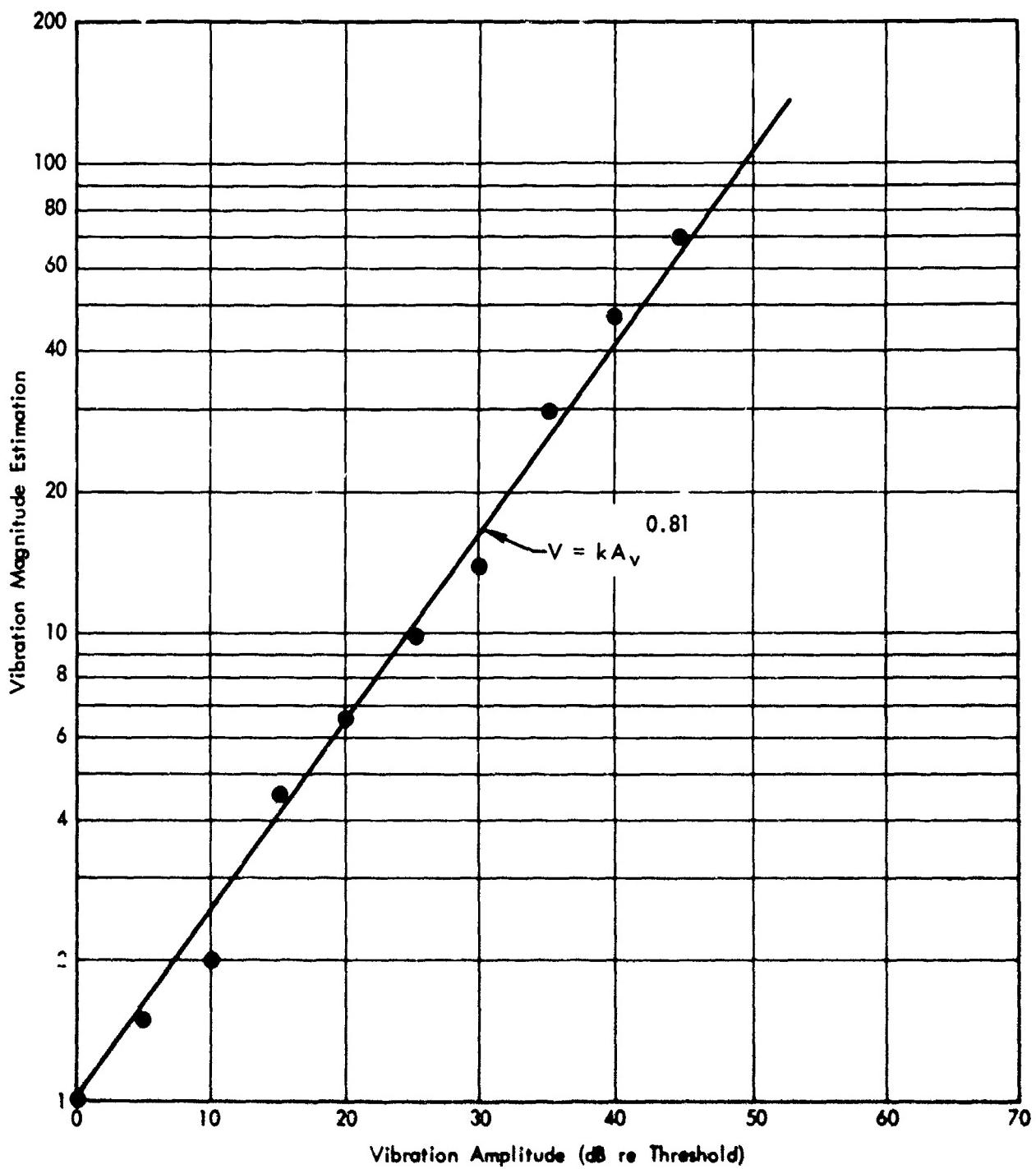
FIGURE 3. MAGNITUDE ESTIMATIONS OF THE APPARENT INTENSITY OF MECHANICAL VIBRATION ON THE FINGER TIP. DATA POINTS REPRESENT THE MEAN JUDGMENTS OF 15 SUBJECTS. NC-50 SHAPED BACKGROUND NOISE SPECTRUM.

B. Primary Test Results

The results of the matching experiments are shown in Figs. 4 through 7. Here the equal sensation functions for the three bands of noise and the vibration are plotted on succeeding figures with increasingly higher overall background noise level. For simplicity, visual best-fit straight line segments were drawn through the data points. The slopes of the primary segments of the equal sensation functions are displayed in Table I. For each set of noise band-vibration functions, the slope value increases monotonically with increasing overall background noise level.*

Growth functions for three third-octave bands of noise are presented in Figs. 8, 9, and 10. Each figure shows the growth function for one frequency and three background noises. These functions have been derived from the vibration magnitude estimation (Fig. 2) and equal sensation results (Figs. 4 through 7) using the procedure described in the following paragraph.

The stimulus sound pressure level for one frequency band is entered as the abscissa in the appropriate equal sensation plot (Figs. 4 through 7). The ordinal value is then determined by the particular curve corresponding to the background noise condition. This ordinal value is the equivalent vibration amplitude in dB and is next used as the abscissa value in Fig. 2. That figure shows the growth of vibration and hence gives the sensation magnitude corresponding to the original stimulus sound pressure level. If this procedure is repeated using a

---

* The departure of some of the points in Figs. 4 through 7 may be attributed to what Stevens (1959[b]) calls a "regression" or "centering" tendency. Although the deviation of the present data from linearity is somewhat larger than that shown in Stevens' 1959 paper, he points out that the magnitude of the regression effect seems to depend on several factors, the most important of which is probably the difficulty of the judgment involved. Thus, it may be suggested that since the task set for the subjects used in this study, that of making judgments based on the acceptability of the stimulus noises rather than simple magnitude or loudness, represented a more difficult situation for the present subjects than for those of Stevens, the observed increase in the regression tendency might be attributed to an increase in task difficulty.

-12-
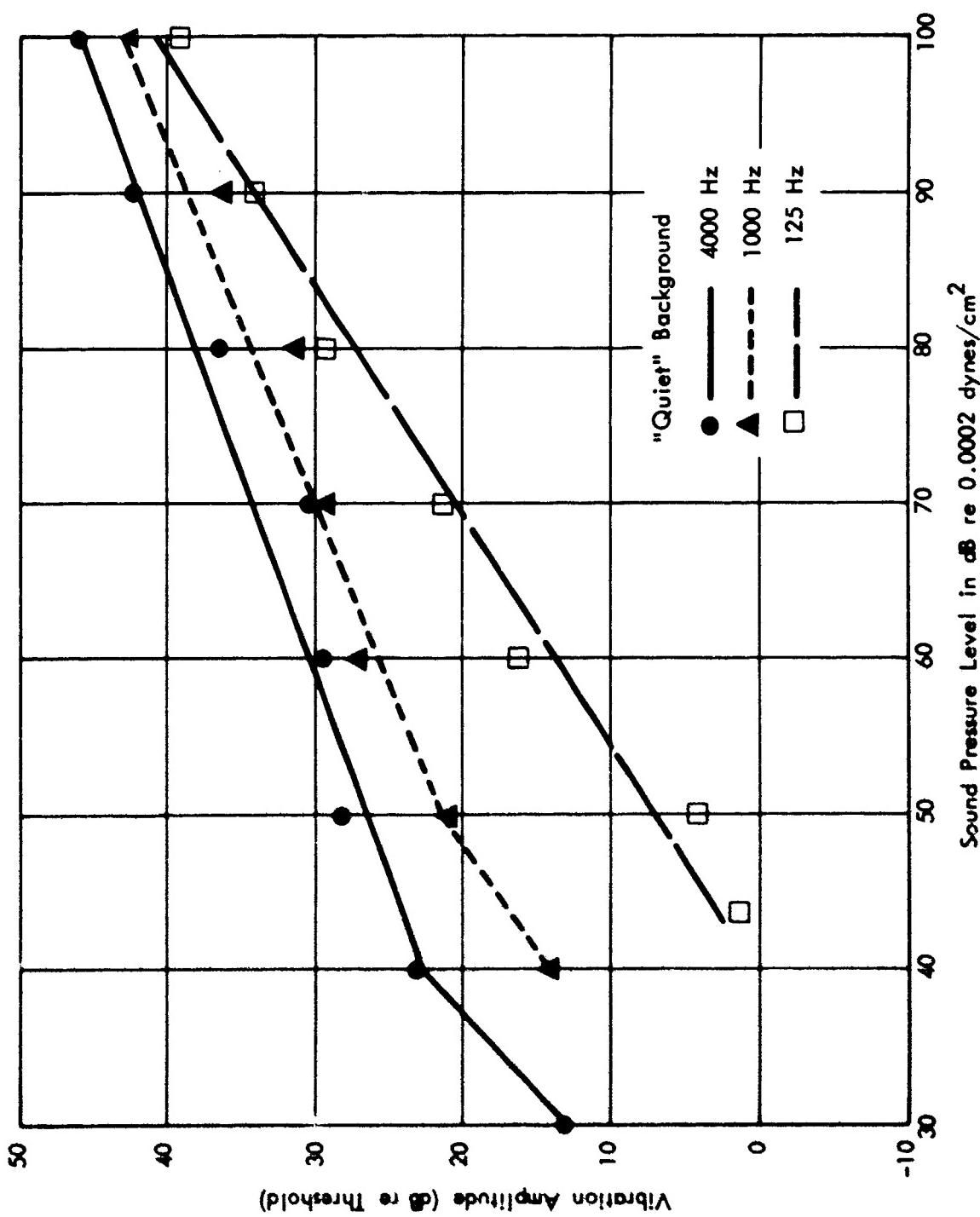
FIGURE 4. EQUAL SENSATION FUNCTIONS FOR 100 Hz VIBRATION APPLIED TO THE FINGER AND NOISINESS OF 1/3 OCTAVE BANDWIDTH NOISES. VIBRATION ADJUSTED TO MATCH NOISINESS

-13-
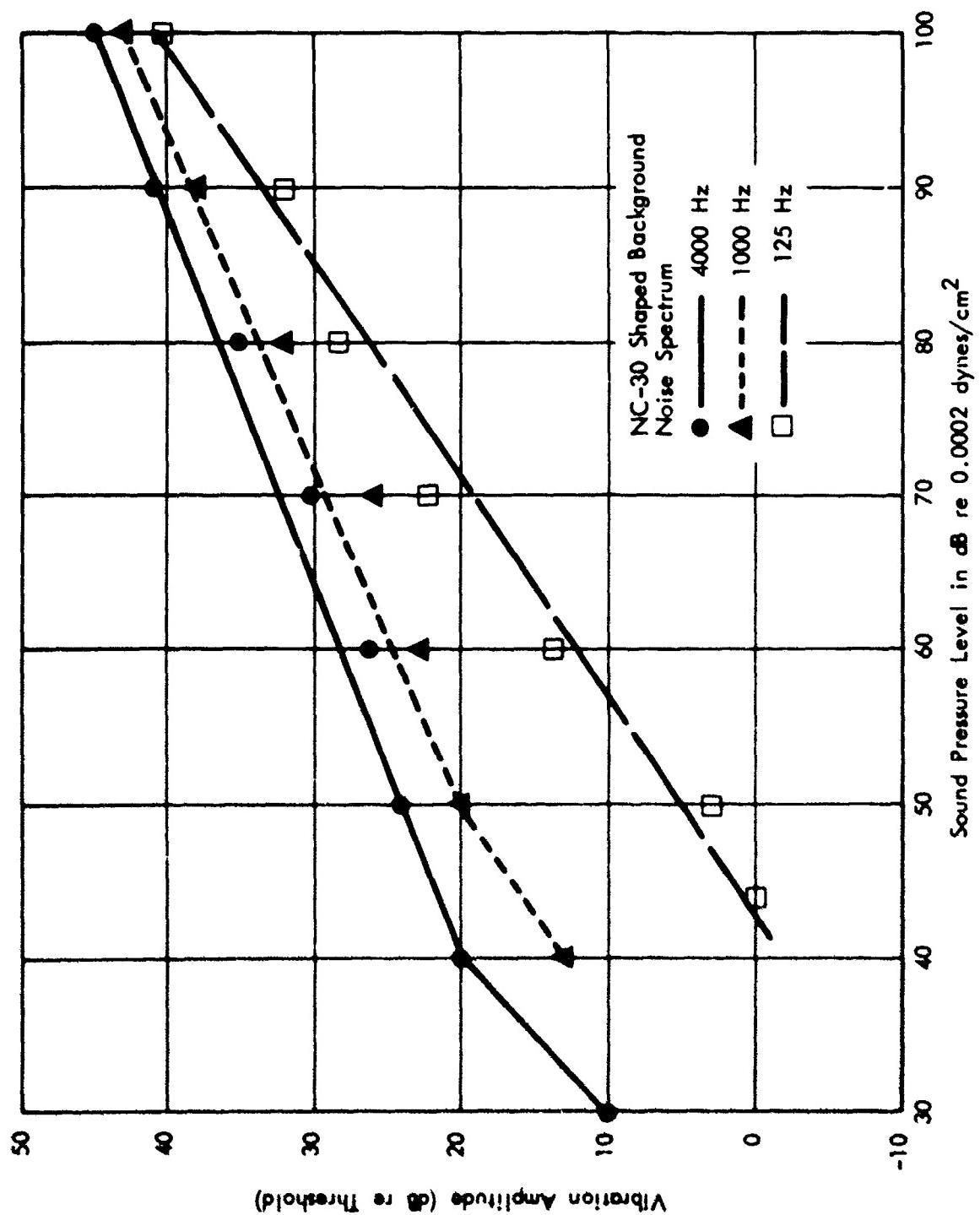
FIGURE 5. EQUAL SENSATION FUNCTIONS FOR 100 Hz VIBRATION APPLIED TO THE FINGER AND NOISINESS OF 1/3 OCTAVE BANDWIDTH NOISES. VIBRATION ADJUSTED TO MATCH NOISINESS
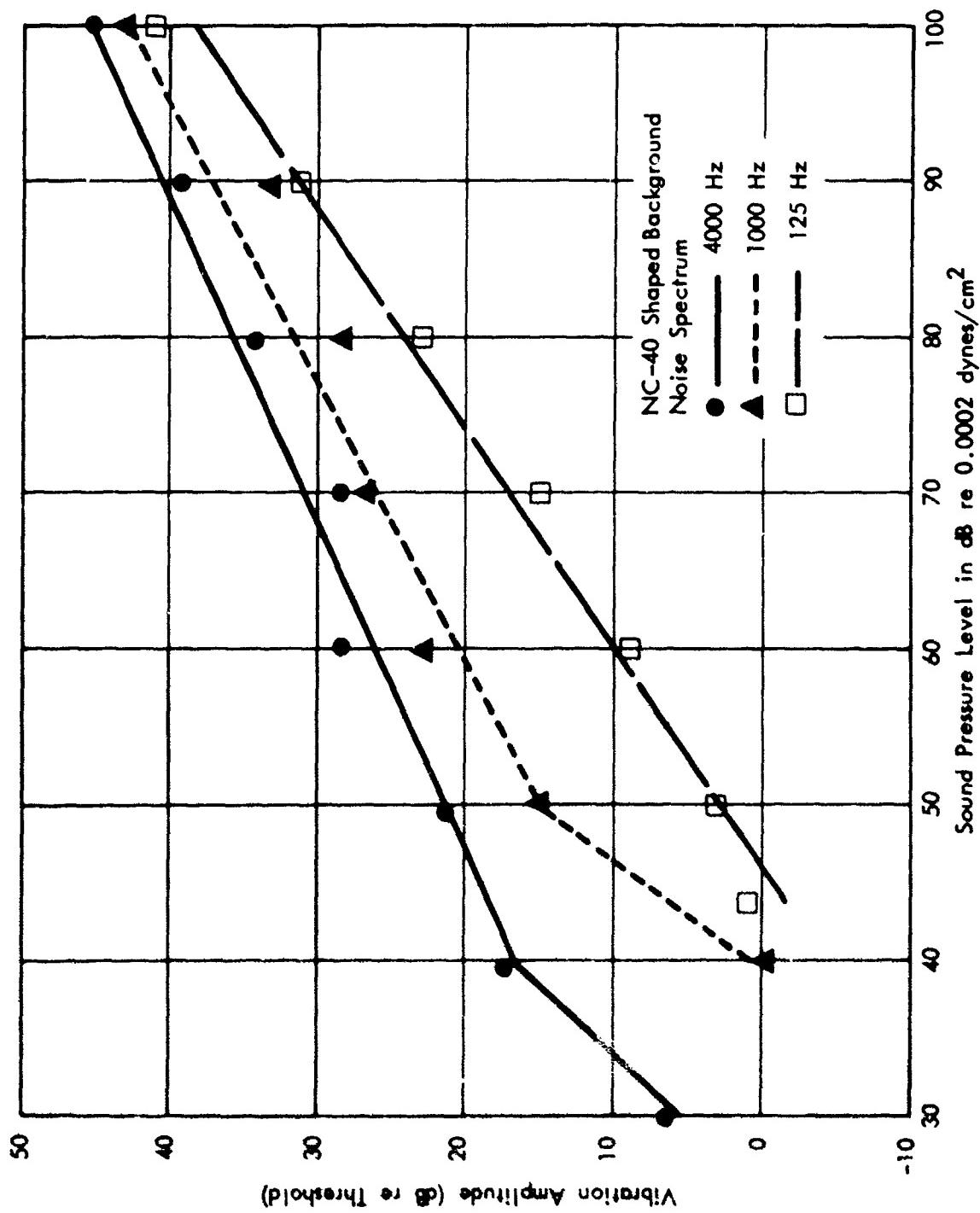
FIGURE 6. EQUAL SENSATION FUNCTIONS FOR 100 Hz VIBRATION APPLIED TO THE FINGER AND NOISINESS OF 1/3 OCTAVE BANDWIDTH NOISES. VIBRATION ADJUSTED TO MATCH NOISINESS

-15-
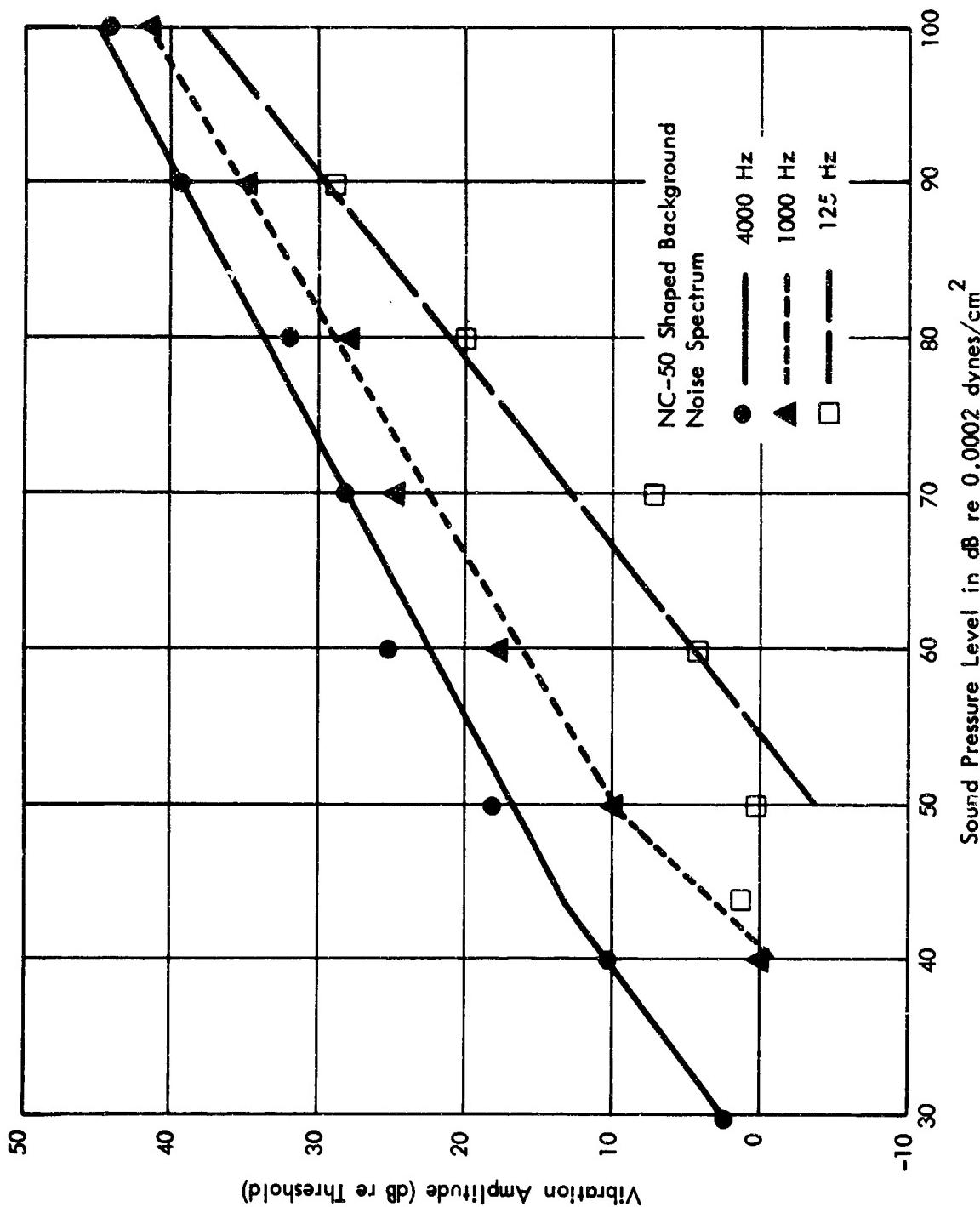
FIGURE 7. EQUAL SENSATION FUNCTIONS FOR 100 Hz VIBRATION APPLIED TO THE FINGER AND NOISINESS OF 1/3 OCTAVE BANDWIDTH NOISES. VIBRATION ADJUSTED TO MATCH NOISINESS.

-16-

TABLE I

SLOPE VALUES FOR EQUAL SENSATION CROSS MODALITY
FUNCTIONS AND SEVERAL BACKGROUND NOISE ENVIRONMENTS

	Quiet	NC-30	NC-40	NC-50
125 Hz Matched with Vibration	0.67	0.68	0.71	0.79
1000 Hz Matched with Vibration	0.43	0.47	0.56	0.63
4000 Hz Matched with Vibration	0.39	0.43	0.48	0.59

NOTE: Slopes are determined from primary segments of curves shown in Fig. 4 through 7.
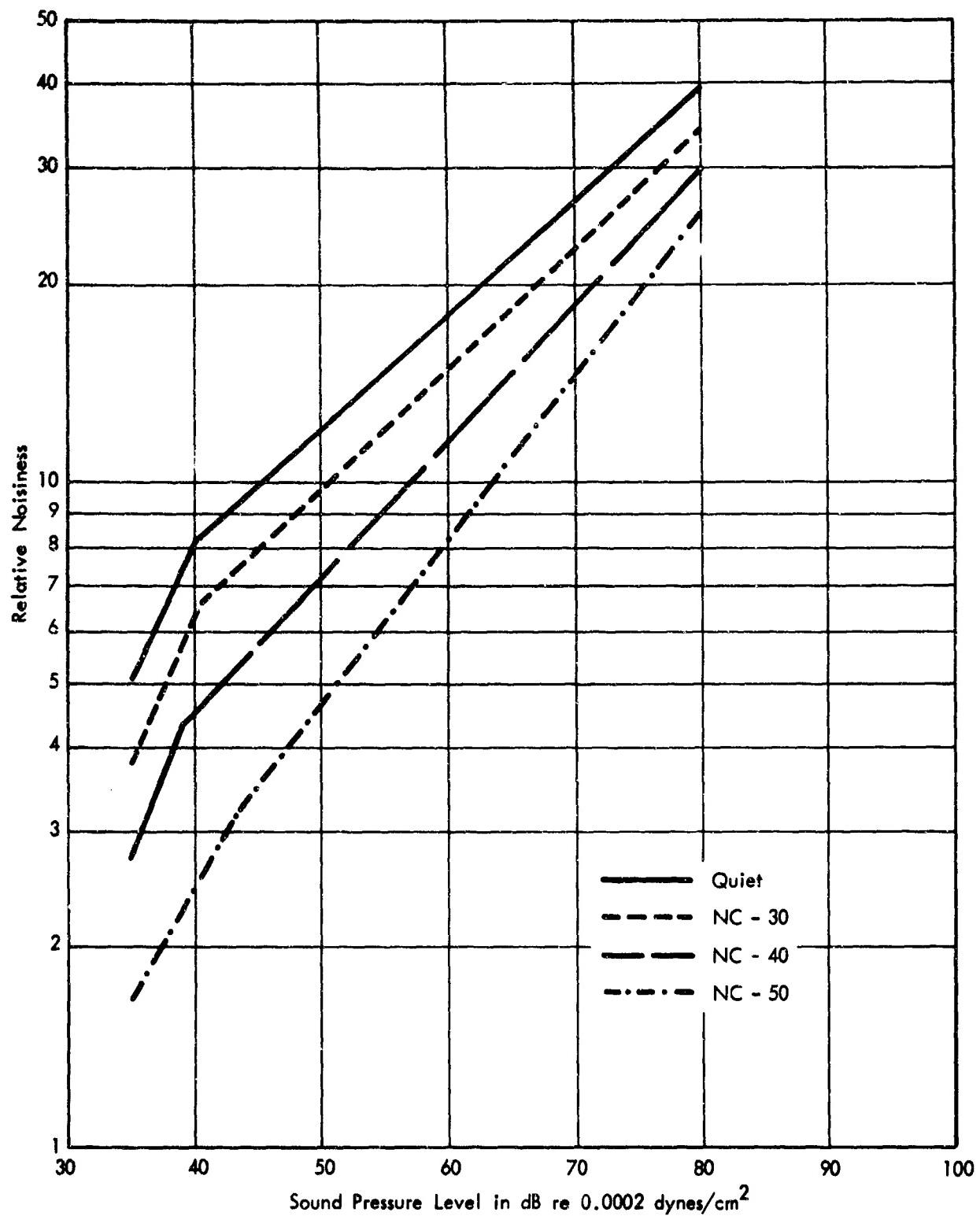
FIGURE 8. GROWTH OF NOISINESS FOR A 4000 Hz CENTER FREQUENCY
1/3 OCTAVE BANDWIDTH NOISE SHOWING THE EFFECT OF VARYING
BACKGROUND NOISE ENVIRONMENTS
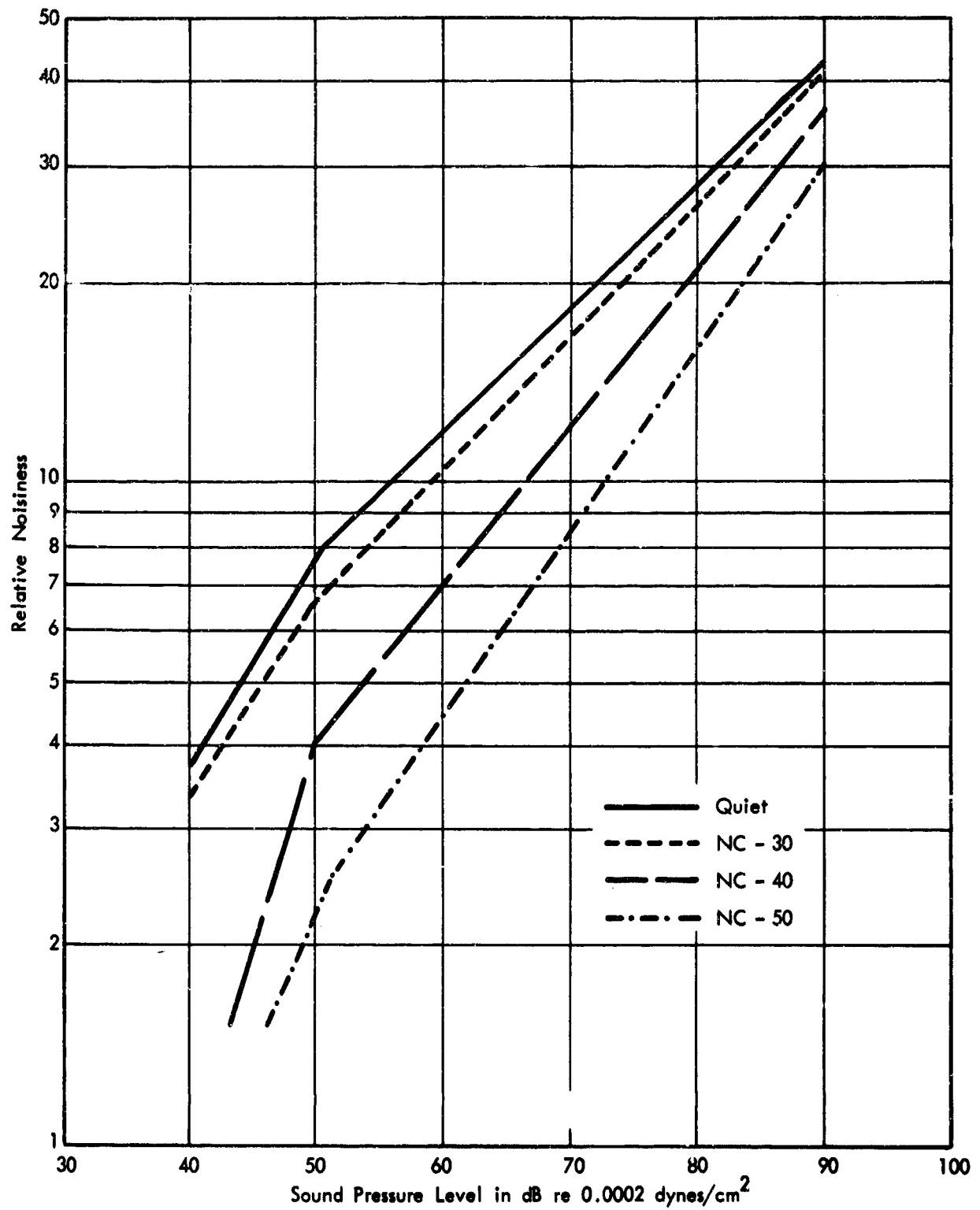
FIGURE 9. GROWTH OF NOISINESS FOR A 1000 Hz CENTER FREQUENCY 1/3 OCTAVE BANDWIDTH NOISE SHOWING THE EFFECT OF VARYING BACKGROUND NOISE ENVIRONMENTS
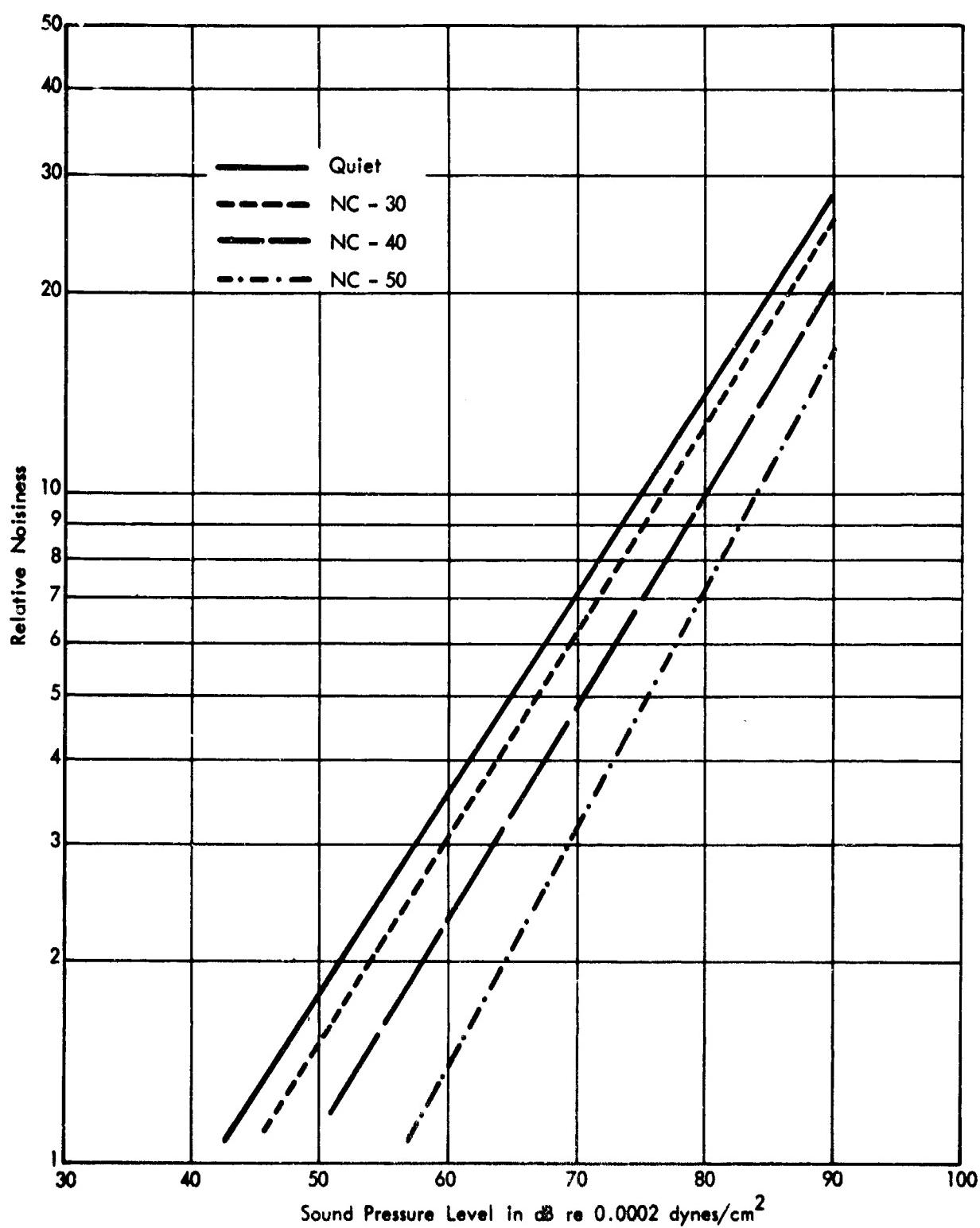
FIGURE 10. GROWTH OF NOISINESS FOR A 125 Hz CENTER FREQUENCY
1/3 OCTAVE BANDWIDTH NOISE SHOWING THE EFFECT OF VARYING
BACKGROUND NOISE ENVIRONMENTS

second sound pressure level, another point is obtained. These two points, then, define a straight line on the noise growth function for a particular frequency and background noise condition. The slope of this straight line is numerically equal to:

$$\frac{n_1}{n_2} \times n_2 = n_1$$

or the desired slope of the noisiness growth function. Both n_1/n_2, which is the slope of the equal sensation function as shown in Table I, and n_2, which is the "slope" (or exponent) of the growth function for vibration, are known.

The process outlined above to arrive at these final growth functions yields only relative forms of the growth functions; it only tells us what the relative slopes of these functions are. The procedure does not fix the vertical spacing of the functions along the subjective scale. It is appropriate to note here that in existing noisiness or loudness calculation schemes for predicting the subjective response of humans to complex sounds, the placement of the growth function along the subjective scale (whether it be noisiness in noys or loudness in sones) is arbitrarily defined so that the 1000 Hz noise band in quiet intersects the 1 noy (or 1 sone) point at a sound pressure level of 40 dB re 0.0002 dynes/cm². Another way of stating this is to say that in the power function describing the growth of loudness or noisiness with increasing sound intensity, given by Eq. 1, the value k_1 may be chosen, without affecting the calculation procedure, to be any useful value.

The effect of background noise on the growth functions is, however, quite evident from the three figures. As overall background noise level increases, the slope of the growth function becomes successively steeper; that is, a given increase in stimulus intensity produces a larger and larger span on the subjective scale. Looking closer at the growth functions for the three bands of noise and quiet background condition, we see that the noisiness of the 125 Hz noise grows most rapidly with intensity or sound pressure level while the 1000 Hz and 4000 Hz noises have approximately the same growth rate. This may be expected from examination of equal noisiness contours, where we observe compression of the contours at low frequency.

The absolute value of the exponent of the power function for the growth of loudness at 1000 Hz, in a quiet environment (i.e., n_1 in Eq. 1) has been determined previously (Stevens, 1955; Reynolds and Stevens, 1960; and others) and generally falls at about 0.6 for sound pressure and binaural listening. Our data, however, reveal a value for n_1 close to 0.4 for the same test conditions but using acceptability or noisiness instructions. The most obvious explanation may be that the cross-modality technique simply underestimates the value of the exponent relative to other methods such as magnitude production. Magnitude estimation, for instance, underestimates relative to the production methods and it has been shown that each of the ratio scaling methods seems to have a certain amount of inherent bias (Stevens, 1959[a]). The results of the present investigation agree most closely with those of Parnell, et al. (1967) who obtained a value close to 0.3 (20 dB per doubling of noisiness) by asking subjects to make magnitude estimates of both tones and bands of noise.

In either case, it is expected that the bias produced by choice of experimental method would be of a constant nature and, therefore, would not affect the desired outcome of the testing; that is, prediction of the relative effect of high background noise levels upon the judged noisiness of a band of noise.

Hellman and Zwislocki (1964) examined the loudness function of a 1000 Hz tone in the presence of a masking or background noise by the so-called method of numerical magnitude balance. This is a combination of the methods of magnitude estimation and production. Their results show a growth function much steeper than that obtained in the present study for a comparable masking noise. That is, from the masked threshold their function rises very steeply to an asymptote with the same growth function tested in quiet.

Lochner and Burger (1961) have suggested that the loudness function for pure tones in the presence of either physiological or external masking noise may be written (See Fig. 11):

$$\psi = k(I^n - I_o^n) \tag{5}$$

where ψ = is noisiness

I = is the pure tone intensity

I_o = is the sum of the physiological noise intensity and the intensity of the external noise in a critical band surrounding the stimulus
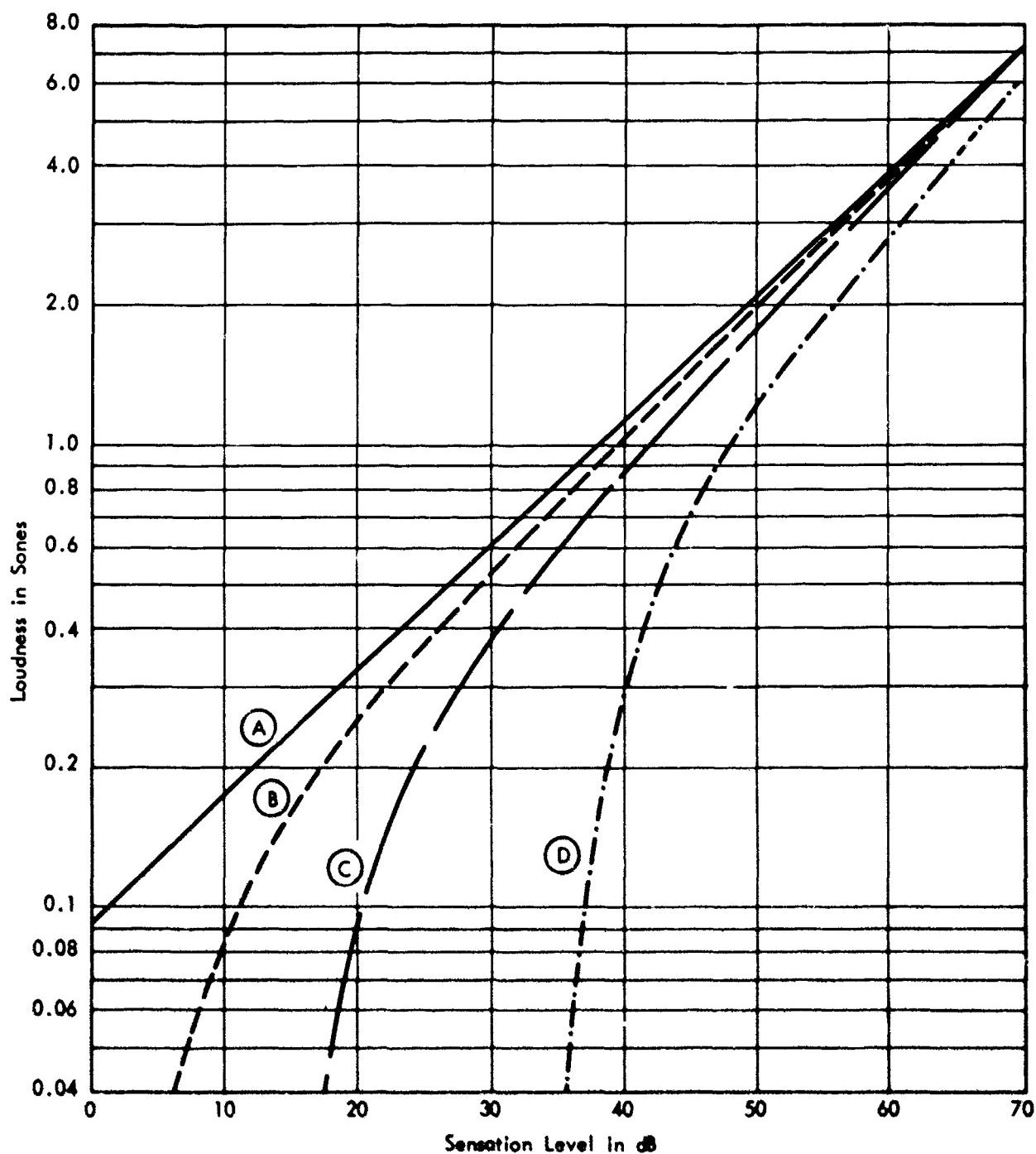
FIGURE 11. LOUDNESS OF A 1000 Hz TONE IN THE PRESENCE OF PHYSIO-
LOGICAL NOISE (CURVE B) AND OCTAVE BAND RANDOM NOISE THAT
GAVE PURE TONE THRESHOLD LEVELS OF 15 dB (CURVE C) AND 35 dB
(CURVE D). STRAIGHT LINE REPRESENTS THEORETICAL GROWTH
FUNCTION UNDER CONDITIONS OF NO MASKING NOISE (CURVE A).
LOCHNER AND BURGER, 1961.

-23-

k = is a constant for a particular frequency sound

n = is an exponent which again depends on sound
       frequency

Their results, plotted with the results from the present investigation and data of Hellman and Zwislocki for approximately the same level of masking noise (both Hellman and Zwislocki and Lochner and Burger used a pure tone as their masked signal whereas the present study used a one-third octave band of noise) are shown in Fig. 12. Both Hellman and Zwislocki and Lochner and Burger's data have been placed at an arbitrary point on the subjective scale, so as to facilitate comparison with the results of this experiment. This is permissible since it was desired to compare only the relative shape and slope of the three growth functions pictured. Lochner and Burger and Hellman and Zwislocki used octave bands of random noise that gave pure tone thresholds of 35 dB and 40 dB sound pressure level respectively. In the present study, wide band random noise was used as the masker. Since in our study, no direct measure of the masked threshold was made, it was necessary to estimate this quantity. The assumption used in making the estimate of the masked threshold was that the masked noise band would just begin to become audible when its power became approximately equal to the power in a critical band with the same center frequency. Since above 100 Hz, a critical band approximates a third octave band, we assumed that the masked threshold would just equal the level of the background noise in the third octave band with the same center frequency.

Using the above assumption, the theoretical loudness or noisiness functions were calculated for the different masked thresholds of the 1000 Hz third-octave band of noise. These functions are plotted in Fig. 13 (curved lines) along with the actual data for the 1000 Hz noise band. Disregarding the separation of the actual data curves (which may be adjusted by a change in the weighting factor k in the power function $\Psi = k(I^n - I_0^n)$ for each individual curve without affecting the slope of the function), it may be seen that for higher level mask' noises (NC40 and NC50 spectra), the actual data and the theoretical functions are approximately parallel for a fair distance along the scale. Only the points at which the actual data breaks downward seem to be displaced somewhat too far to the left of the figure. However, since in the break point region, few data points were taken, the true shape of the data from this investigation may be somewhat different than that depicted in the figures.
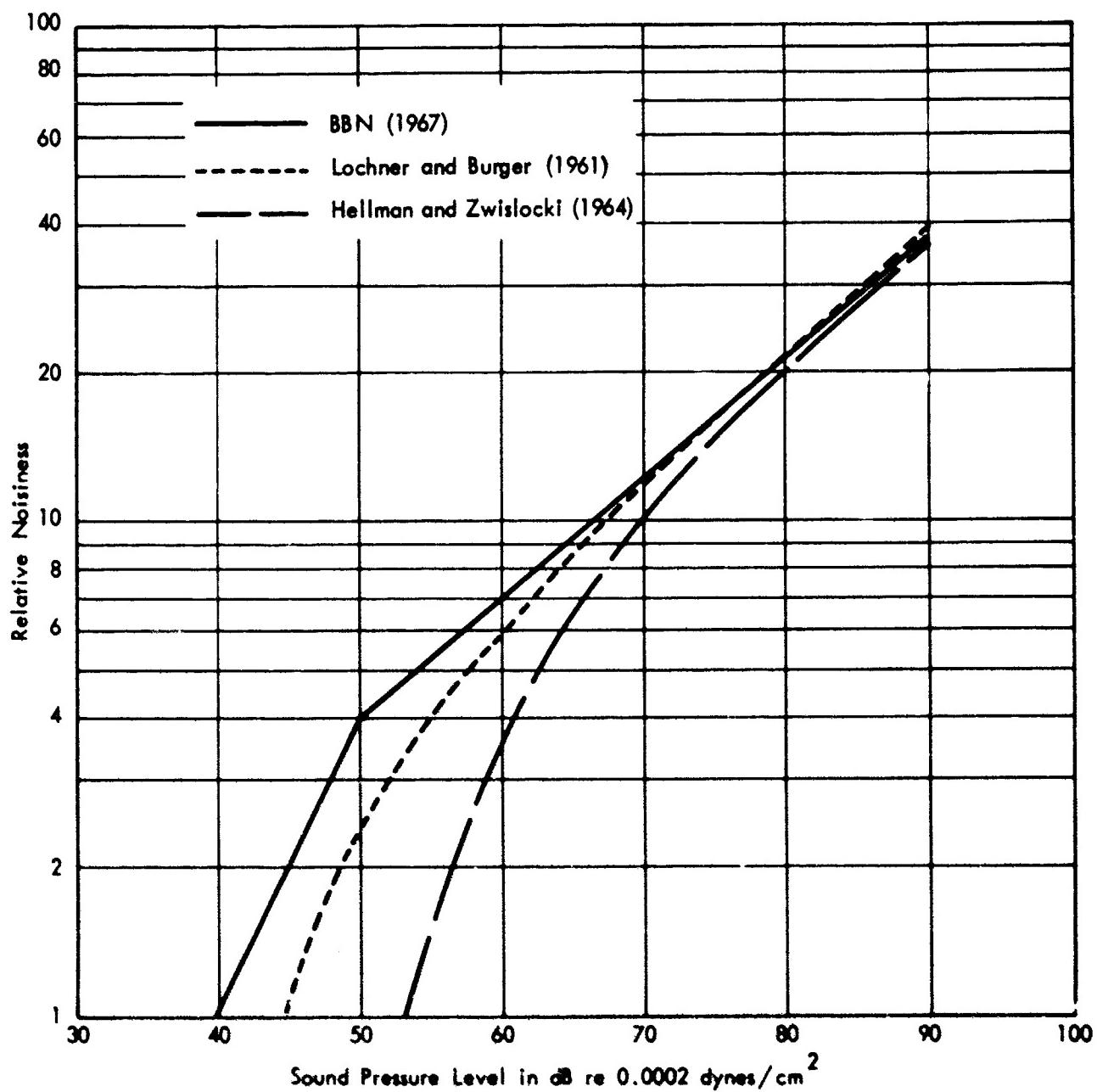
FIGURE 12. COMPARISON OF SEVERAL INVESTIGATIONS FOR GROWTH
OF NOISINESS (BBN) AND LOUDNESS (LOCHNER & BURGER, 1961;
HELLMAN & ZWISLOCKI, 1964) IN THE PRESENCE OF BACKGROUND
NOISE. BACKGROUND NOISE WAS SUCH THAT IT PRODUCED MASKED
THRESHOLDS OF 38 dB (BBN), 35 dB (LOCHNER & BURGER) AND 40 dB
(HELLMAN & ZWISLOCKI) IN THE MASKED TONE OR NOISE. RESULTS
ARE FOR 1000 Hz.
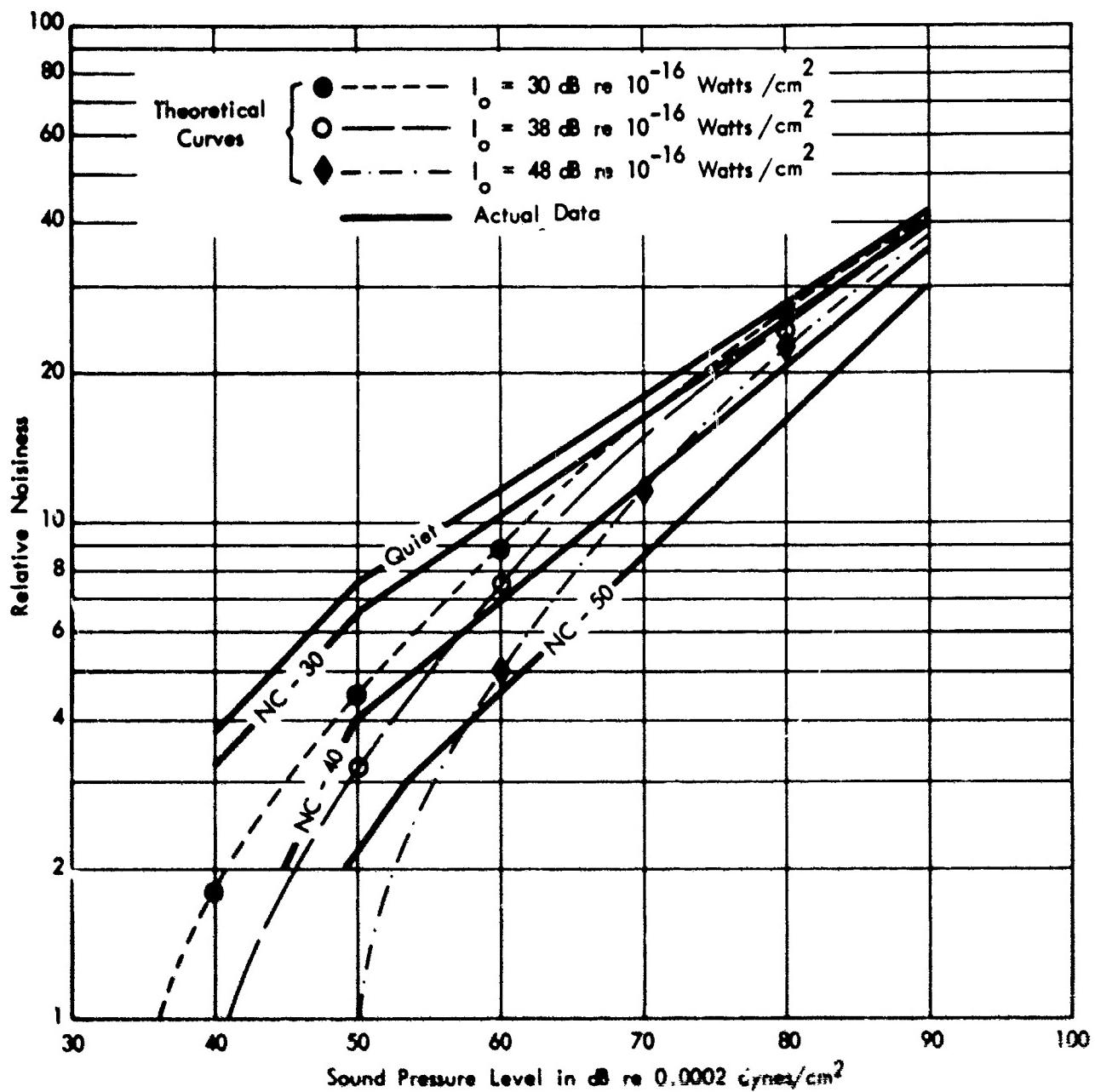
FIGURE 13. COMPARISON OF BBN DATA FOR GROWTH OF NOISINESS AT 1000 Hz WITH VARYING BACKGROUND NOISE LEVELS AND THEORETICAL CURVES COMPUTED FROM THE FUNCTION $\psi = k (I^n - I_o^n)$ WHERE I_o IS THE THRESHOLD INTENSITY FOR THE MASKED NOISE (SEE TEXT)

Further deviations from both the Hellman and Zwislocki and Lochner and Burger data may be partially explained by the fact that the present study used third octave bands of noise as stimuli whereas the other investigators used pure tone stimuli.

Lochner and Burger's hypothesis of the form of the growth function for loudness in the presence of a masking noise suggests that a given masking noise reduces the loudness of a masked tone at all levels by a constant amount. For higher levels of background noise, the data of Lochner and Burger and those of the present investigation are largely in agreement except for differences as noted above. Thus, it might be tentatively proposed that the same holds true for the growth of noisiness of a band of noise in a broadband background noise.

This tentative hypothesis would be subject to imposition of certain criteria on the background noise spectra, the most important of which is that there be no prominent peaks or valleys in the spectrum, so that the only important masking components are those in a critical band around the stimulus. Otherwise, the effect might be confounded by the upward spread of masking due to the more spectrally removed components of the masking noise.

V. DEVELOPMENT OF A CALCULATION PROCEDURE TO ACCOUNT FOR EFFECTS OF BACKGROUND NOISE IN THE PERCEIVED NOISE LEVEL CALCULATION

A. Derivation of the Procedure

The foregoing analysis suggests several methods by which a calculation procedure might be developed to account for the effects of background noise upon the judged noisiness of complex stimuli. These methods would constitute a modification of the existing perceived noise level calculation.

The first of the methods is based upon the assumption that a given background noise changes the judged noisiness of a band of noise by a constant amount, that amount determined by the level of the background noise within the critical band (i.e., approximately a one-third octave band) with the same center frequency as the judged band. Thus, a table could be formed with independent parameters of third octave band level (of the background noise) and third-octave band center frequency (of the judged noise) whose entries would be the amount, in noys, to be subtracted from each third-octave band noy value of the judged stimulus, for a given background noise. In applying this correction, the noisiness of each third octave band of the judged noise would be computed using the tabulated noy values of Kryter and Pearsons (1963). From each of these computed values, an appropriate quantity of noys would be subtracted according to table above. The total noisiness of the judged noise could then be calculated and converted to perceived noise level in the same manner as is done at the present. This method is based upon the assumption that a given background noise affects the judged noisiness of a band of noise by a constant amount, depending only upon the level of the background noise. The calculation scheme would be based, then, upon a theoretical model and not directly upon observed data, although to be sure, the observed data appears to fit the model to a large extent.

There is another more direct method, however, by which no assumptions need be made, except perhaps that the growth of noisiness in quiet follows a power law relation as has been shown for loudness. It is not necessary in this second method to derive the noisiness growth functions from the cross-modality data. Thus the cross-modality data, in terms of the equal sensation function plots, may be used directly to predict the effect upon judged noisiness.

It is necessary that the cross-modality data be replotted (see Figs. 14, 15, and 16) so that it is grouped according to frequency rather than background noise condition. Thus, Fig. 14 contains all the data gathered at 125 Hz for all four background noise conditions. The same may be seen for the 1000 Hz and 4000 Hz noise band, respectively, in Figs. 15 and 16. For each frequency and background noise condition, data may be tabulated as in Table II on the following page (which only depicts data for the 1000 Hz noise band). Column I is the sound pressure level of the judged stimulus. Column II is obtained by finding the difference in dB, for the sound pressure level given in Column I, between the vibration amplitude in quiet and vibration amplitude for a particular background noise condition. Column III is the ratio between the stimulus sound pressure level (for the sound pressure level given in Column I) and the sound pressure level of background noise in the same one-third octave band. To find the entries in Column IV, it is necessary to first calculate a least squares regression line for the matching data of each of the three frequencies determined in the quiet background noise environment. The slope of this line will give us, for a particular frequency, the relation between a change in vibration amplitude in dB and a change in sound pressure level in dB. Column IV then, is found by dividing each entry in Column II by the appropriate slope value given by the regression line and represents the difference in sound pressure level in dB due to a particular background noise condition. The assumption used here is that over a major portion of its length, the matching or equal sensation function, determined in an acoustically quiet environment, approximates a linear relation when log vibration amplitude is plotted versus log sound pressure.

The data of Table II is summarized in Fig. 17 where change in sound pressure level due to background noise, in dB, (i.e., Column IV entries) is plotted against stimulus-noise-to-background-noise ratio in dB. In constructing this figure, data taken in the NC30 background environment were not used due to the similarity between these background noise levels and those measured for the "quiet" background condition (as shown by Fig. 1). Two straight line segments were constructed through the data points visually in order to obtain a best-fit approximation.
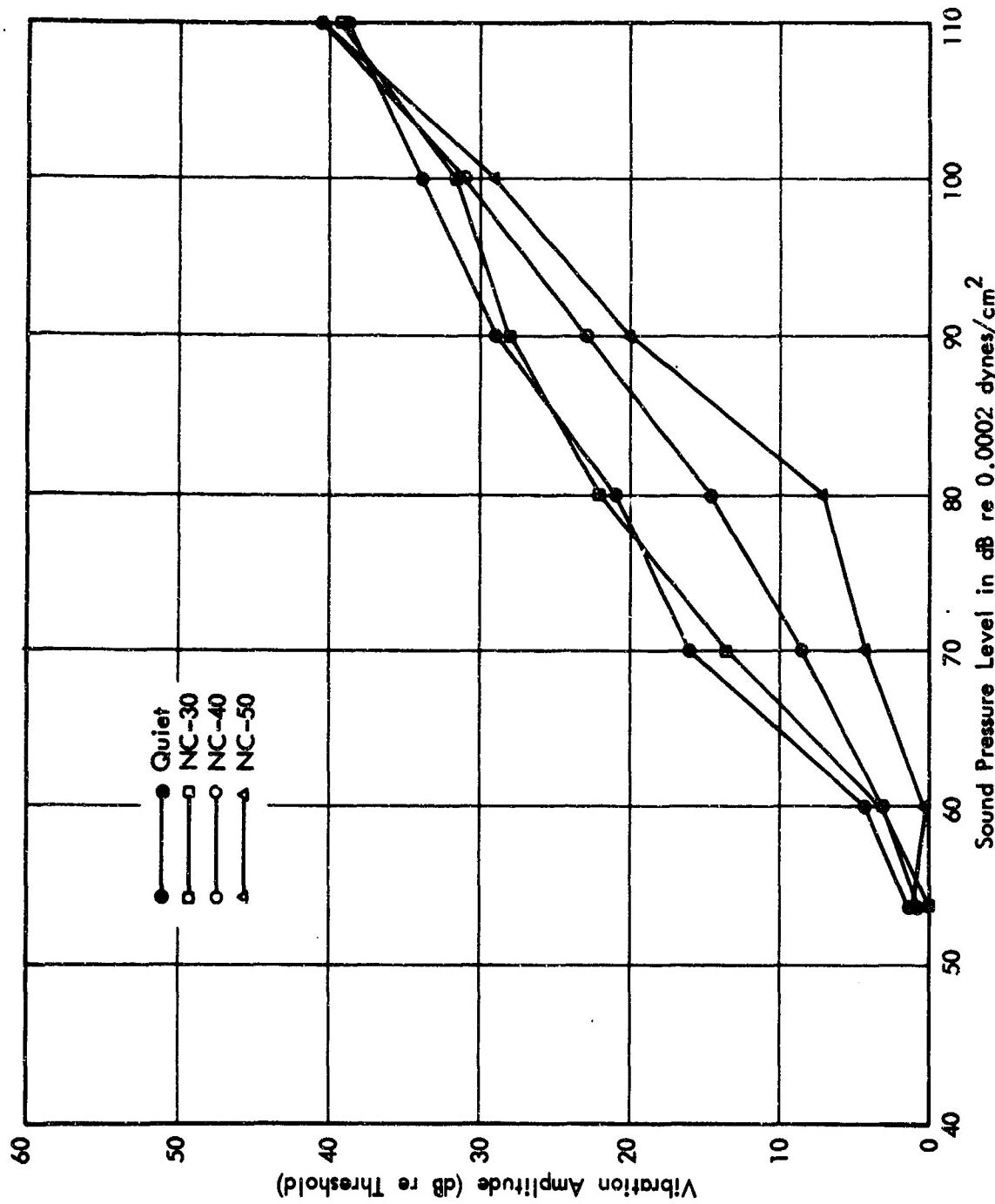
FIGURE 14. EQUAL SENSATION FUNCTIONS FOR A 100 Hz VIBRATION APPLIED TO THE FINGER AND NOISINESS OF A 125 Hz, 1/3 OCTAVE BANDWIDTH NOISE UNDER VARYING BACKGROUND CONDITIONS. VIBRATION ADJUSTED TO MATCH NOISINESS.

-30-
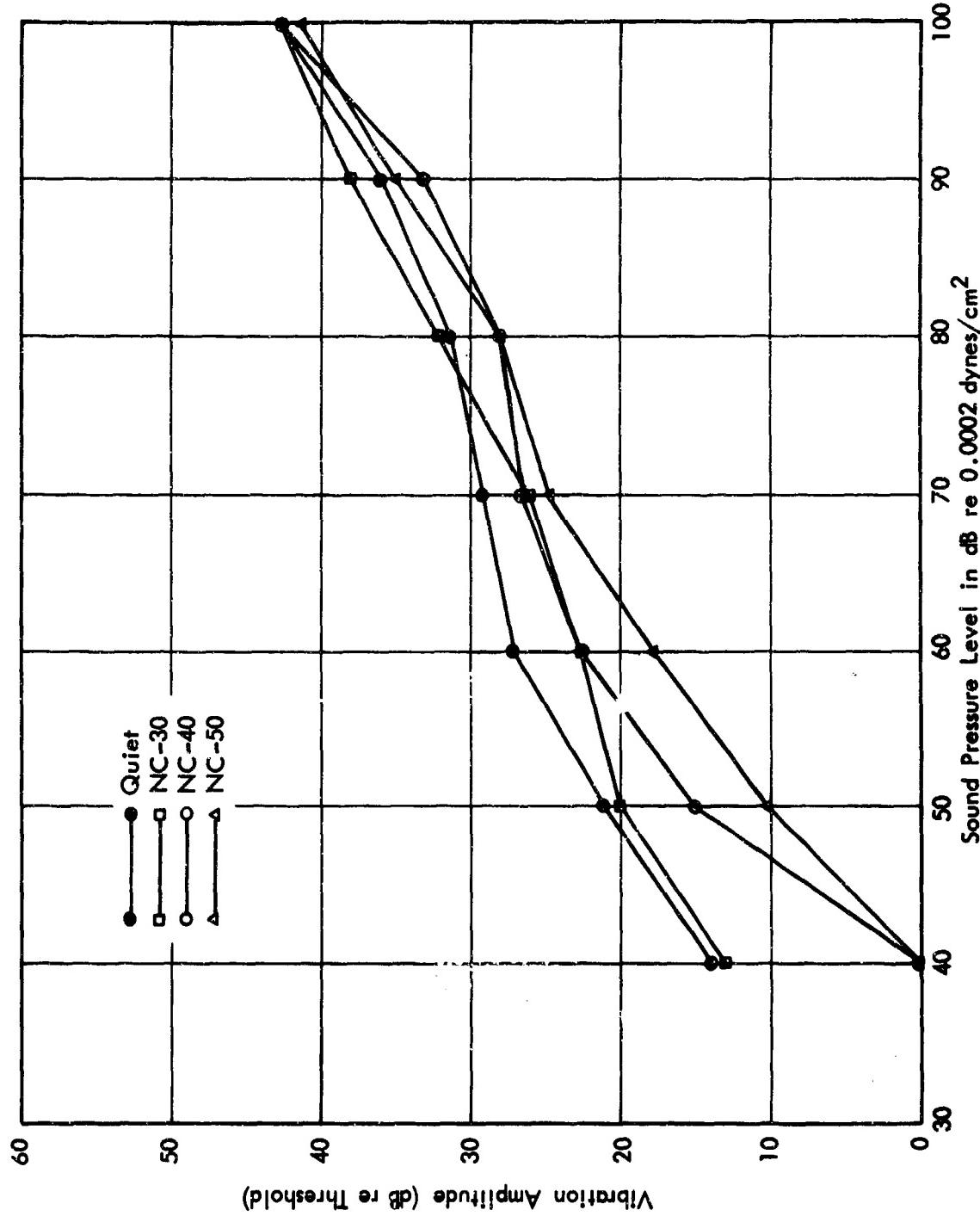
FIGURE 15. EQUAL SENSATION FUNCTIONS FOR A 100 Hz VIBRATION APPLIED TO THE FINGER AND NOISINESS OF A 1000 Hz, 1/3 OCTAVE BANDWIDTH NOISE UNDER VARYING BACKGROUND CONDITIONS. VIBRATION ADJUSTED TO MATCH NOISINESS.
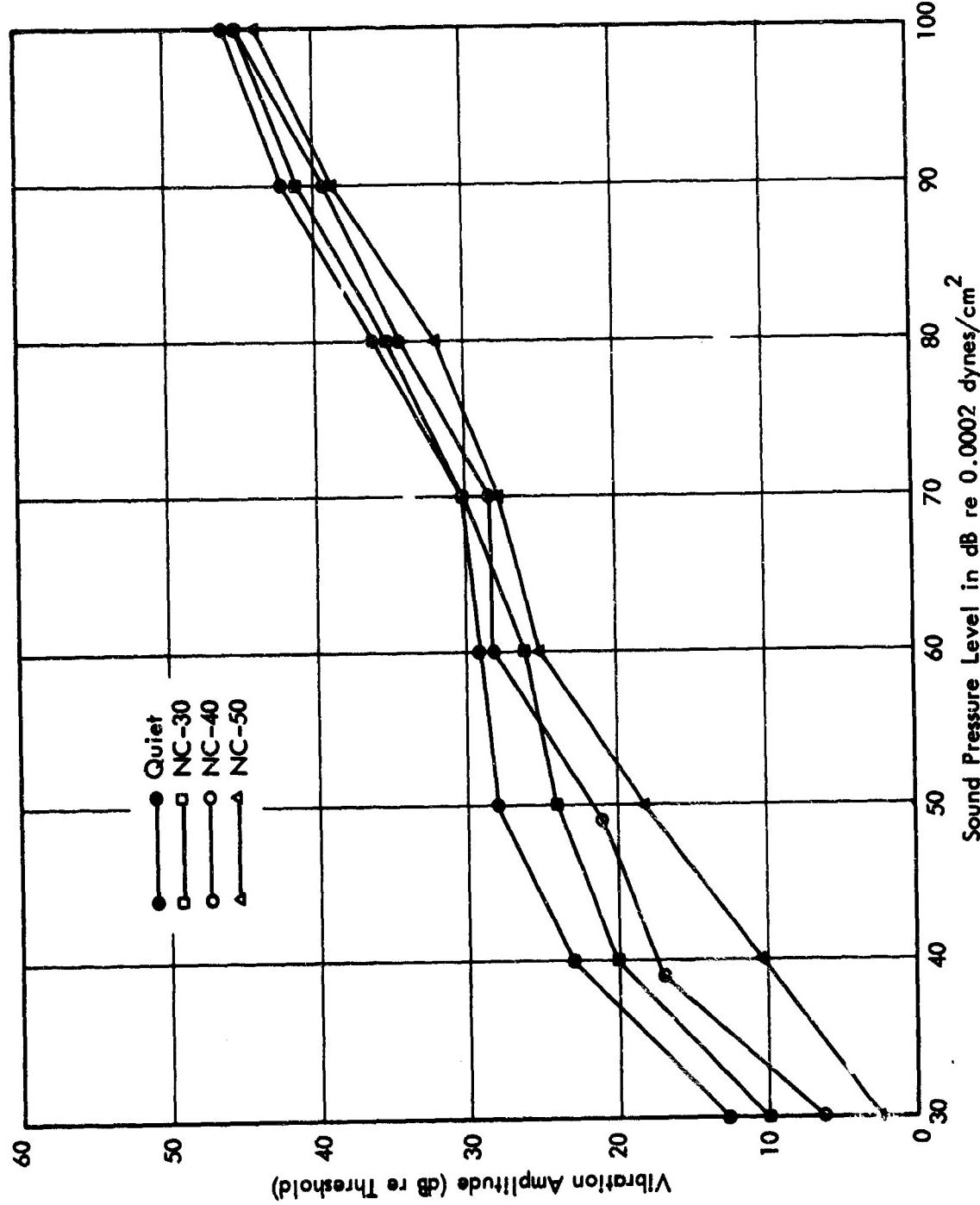
FIGURE 16. EQUAL SENSATION FUNCTIONS FOR A 100 Hz VIBRATION APPLIED TO THE FINGER AND NOISINESS OF A 4000 Hz, 1/3 OCTAVE BANDWIDTH NOISE UNDER VARYING BACKGROUND CONDITIONS. VIBRATION ADJUSTED TO MATCH NOISINESS.

-32-

TABLE II
EXAMPLE OF PROCEDURE USED TO OBTAIN DATA
OF FIG. 17 AT 1000 Hz

Background Noise	I Sound Pressure Level (dB)	II Δ Vibration Amplitude at Constant SPL (dB)	III Stimulus-Noise-to-Background Noise Ratio (dB)	IV Δ Sound Pressure Level (dB)
NC-30	40	1	10	2.4
NC-30	50	1	20	2.4
NC-30	60	4	30	9.5
NC-30	70	3	40	7.1
NC-30	80	-1	50	-2.4
NC-30	90	-2	60	-4.8
NC-30	100	0	70	0
NC-40	40	14	2	32.0
NC-40	50	6	12	14.3
NC-40	60	4	22	9.5
NC-40	70	2.5	32	6.0
NC-40	80	3	42	7.1
NC-40	90	3	52	7.1
NC-40	100	0	62	0
NC-50	40	14	-8	32.0
NC-50	50	11	2	26.2
NC-50	60	9	12	21.4
NC-50	70	4	22	9.5
NC-50	80	3.5	32	8.3
NC-50	90	1	42	2.4
NC-50	100	1.5	52	3.6

FIGURE 17. RELATION BETWEEN EFFECT OF BACKGROUND NOISE AND STIMULUS TO NOISE RATIO

The following equations represent these lines:

$$\Delta SPL = -0.9\ S + 28,\ 0 \le S \le 25 \tag{6}$$

and,

$$\Delta SPL = -0.14\ S + 9,\ 25 < S \le 65 \tag{7}$$

where S   is the signal-noise-to-background-noise ratio
            in dB for a one-third octave band,

Δ SPL is the difference in sound pressure level in
            dB due to a particular background noise.

This data suggests a direct method by which the perceived
noise level calculation might be modified to account for the
effects of background noise. In applying this calculation
scheme, the third-octave band spectrum for a noise, such as
an aircraft flyover would be measured. The third-octave band
spectrum of the steady or relatively constant background noise
would also be measured and the difference in sound pressure
level for a given frequency band between the judged noise and
the background noise would be computed. Each band level of
the stimulus noise would then be adjusted according to the
stimulus-noise-to-background-noise ratio of that particular
band, by an amount equal to that indicated along the ordinate
in Fig. 17. Perceived noise level would then be calculated
for this adjusted spectrum.

A band-by-band correction procedure such as this would
have the advantage over an overall noise level procedure in
that it would differentially account for different noise
spectrum shapes. The procedure would be insensitive, how-
ever, to background spectra in which prominent peaks or
valleys occur. In these cases, there would be masking by
the peak spectral components outside the critical band or
bands in which the peaks occur. Thus, the requirement must
be made here that this calculation scheme should only be
used in the cases in which there are no prominent peaks
in the background spectrum.

B. Verification of the Procedure

The procedure was evaluated by applying it to some noises which had been judged in various levels of background noise. Pearsons (1966) had subjects rate various real and artificial sounds in varying levels of the same background noise by means of category scales. He then plotted his results as the difference in noisiness due to the background noise in PNdB versus the overall stimulus-noise-to-background-noise ratios 'in PNdB.

Three of Pearsons' stimuli were chosen, two real-life fly-over spectra and one simulated jet noise. For each of these stimuli, at a given overall sound pressure level, and all the background noise conditions used by Pearsons, the correction procedure outlined in Section A above was applied. The results of those calculations are shown in Table III. The data were then plotted, along with Pearsons' empirical data, in Fig. 18. On this figure, it may be noticed that the calculated data all seems displaced somewhat to the right of the empirical data. There is some overlap, however, and the general trend of the data appears the same in both cases. The results are clearly of the same order.

It was also desired to see if the approach used and the final model employed in the calculation scheme is consistent with the type of model proposed by Lochner and Burger, and earlier in this report. Data from Figs. 13 and 17 were used in this comparison. The results are shown in Fig. 19. The straight lines in this figure represent the best fit to the empirical data of this investigation (the equations for these lines are given by Eqs. 4 and 5). The data points were obtained from Fig. 13 by measuring, for a given noisiness value, the difference in SPL between a point on the empirical quiet growth function and the corresponding point on the theoretical growth functions for the NC40 and NC50 background noise conditions. This process was repeated for a number of subjective noisiness levels to give a spread of data points.

The results of this comparison show a very close agreement between the theoretical and empirical data. It may thus be concluded that the calculation procedure both predicts to a degree the judgments of human subjects and correlates well with the theoretical model as first proposed by Lochner and Burger.

TABLE III

RESULTS OF APPLYING PROPOSED BACKGROUND NOISE
CORRECTION SCHEME TO PEARSONS' 1966 STIMULI

| Stimulus	Perceived Noise Level In Quiet (PNdB)	Background Noise Perceived Noise Level (PNdB)	Stimulus-Noise-to-Background-Noise Ratio (PNdB)	Calculated Perceived Noise Level In Noise (PNdB)	Calculated Difference In Noisiness Due to Background Noise (PNdB)
Flyover #1	106.5	80	26.5	102.1	4.4
Flyover #1	106.5	64	42.5	103.4	3.2
Flyover #1	106.5	47	59.5	105.8	0.7
Flyover #2	108.4	80	28.4	102.8	5.6
Flyover #2	108.4	64	44.4	106.0	2.4
Flyover #2	108.4	47	61.4	107.9	0.5
Simulated Jet	101.0	80	21.0	94.2	6.8
Simulated Jet	101.0	64	37.0	97.8	3.2
Simulated Jet	101.0	47	54.0	99.5	1.5
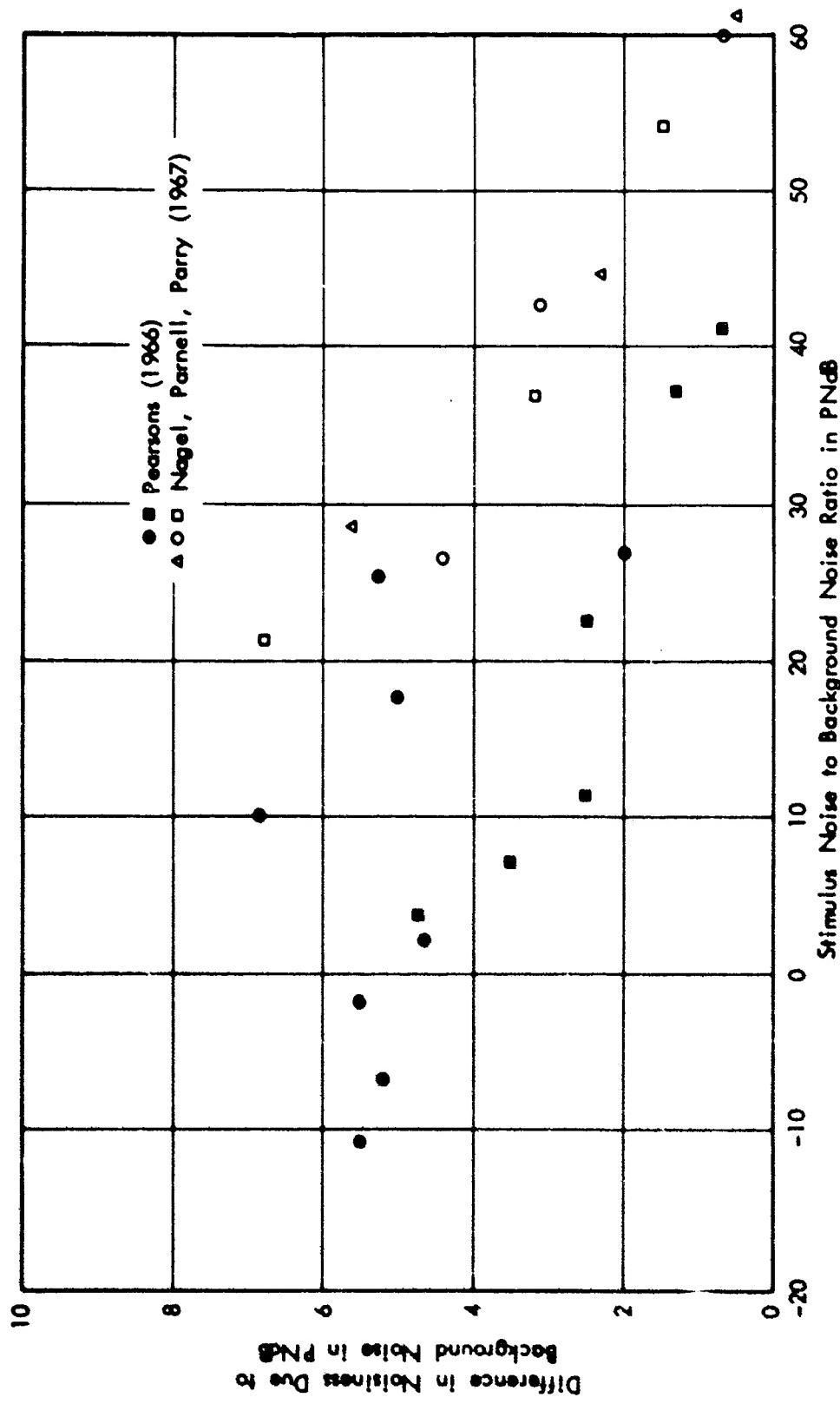
FIGURE 18. COMPARISON OF PEARSON'S 1966 DATA WITH THAT OF THE PRESENT INVESTIGATION

-38-
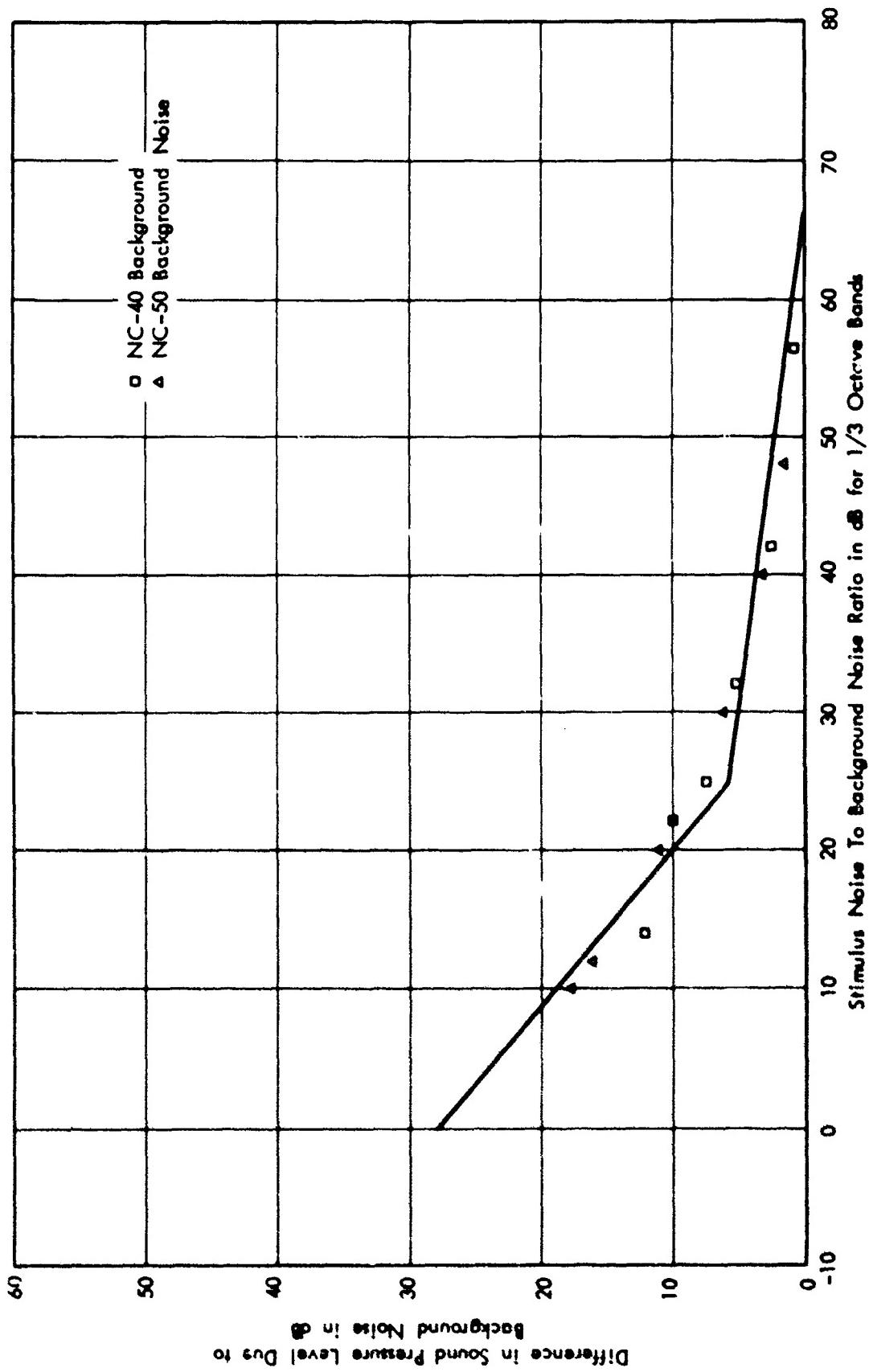
FIGURE 19. COMPARISON OF EMPIRICAL DATA (SOLID LINE) WITH DATA (POINTS) COMPUTED FROM LOCHNER AND BURGER'S 1961 MODEL

-65-

VI. SUMMARY AND CONCLUSIONS

The following conclusions may be drawn from the results of these investigations:

1. The slope of the growth of noisiness function for one-third octave bands of noise appears to be systematically affected by the addition of a spectrally smooth background noise to the test environment. Such a background noise causes the judged noisiness of a narrow band of noise to be reduced approximately by a constant amount at all sound pressure levels. This amount depends, in the absence of any prominent peaks or valleys in the background noise spectrum, upon the power of the masking noise in a critical band surrounding the stimulus.

2. A calculation scheme to account for the effects of background noise upon perceived noise level has been developed and may be outlined as follows:

   a. Determine the one-third octave band spectral values of both the judged intrusive noise (such as an aircraft flyover) and the steady background noise.

   b. For each frequency band determine the ratio of the sound pressure level of the judged noise to the sound pressure level of the background noise, in dB.

   c. Determine a correction for each frequency band according to the following relationships:

   $$\Delta \text{SPL} = - 0.9 \, S + 28 \ (dB), \ 0 \leq S \leq 25$$

   $$\Delta \text{SPL} = - 0.15 \, S + 9 \ (dB), \ 25 < S \leq 65$$

   $$\Delta \text{SPL} = 0 \qquad\qquad S \geq 65$$

d. Subtract the appropriate correction (Δ SPL)
    from each frequency band sound pressure level
    of the judged noise,

e. Convert the corrected third-octave band spectrum
    levels to noys via Kryter and Pearsons" 1963
    tables, and compute the perceived noise level
    in PNdB. This scheme is consistent with the
    model outlined in 1 above and human judgments
    of various types of sounds.

3. For signal-noise-to-background-noise ratios of greater
    than approximately 65 dB, the band correction approaches
    zero. Thus, no correction need be applied to spectra
    for which the signal-to-background-noise ratio (by
    bands) exceeds 65 dB. The effect, however, upon the
    perceived noise level of a judged noise with realistic
    background noise spectra and signal-noise-to-background-
    noise ratios of 40 dB, is approximately 3 PNdB with
    the exact amount dependent of course upon the shape of
    the background and stimulus spectra. Thus, in practice,
    it may be advantageous to consider an even lower
    signal-noise-to-background-noise ratio, above which
    no correction need be applied.

    For a given background noise and signal, the total
    effect upon the perceived noise level in PNdB as
    predicted by this calculation scheme is somewhat
    less than the individual band corrections might
    indicate. This may be attributed to the way in which
    the perceived noise level calculation sums the noisi-
    ness values of the individual bands into the total
    noisiness in noys and then converts to perceived noise
    level in PNdB.

4. The calculation procedure developed is particularly
    applicable to vehicle noises, such as noise produced
    by aircraft flyovers. It may prove useful in other
    noise/background noise stiuations, however, in which
    the background noise spectra are relatively smooth,
    continuous, and steady.

5. The growth of noisiness function for a narrow band of
    noise behaves somewhat like the modified power func-
    tion proposed by Lochner and Burger (1961) for loud-
    ness.

6. The slope of the growth function for noisiness of a
   1000 Hz one-third octave band of noise determined
   in this test in a relatively quiet acoustical en-
   vironment is not entirely in agreement with that
   determined by previous investigators for loudness
   and noisiness. The present investigation yields a
   growth rate of 17 dB per doubling of noisiness. The
   results of these tests are most closely matched by
   those of Parnell, Nagel and Parry (1967) obtained
   using the method of magnitude estimation (20 dB per
   doubling) and Bishop (1966) in which subjects judged
   relative acceptability of aircraft flyovers (16 dB
   per doubling).

7. The relative slopes of the noisiness functions deter-
   mined in quiet for the 125 Hz and 4000 Hz narrow
   bands of noise, are generally in agreement with
   previous investigations. Thus, the 125 Hz noise
   grows much more rapidly with stimulus intensity
   than either the 1000 Hz or 4000 Hz noises, which
   have approximately equal growth rates. This rela-
   tion is illustrated in virtually all existing sets
   of equal loudness and noisiness contours by com-
   parison of the contours for frequencies below 1000 Hz.

REFERENCES

D. E. Bishop (1966), "Judgments of the Relative and Absolute Acceptability of Aircraft Noise", J. Acoust. Soc. Am., 40, 108.

R. P. Hellman and J. Zwislocki (1964), "Loudness Function of a 1000-cps Tone in the Presence of Masking Noise", J. Acoust. Soc. Am., 36, 1618.

K. D. Kryter (1959), "Scaling Human Reactions to the Sound from Aircraft", J. Acoust. Soc. Am., 31, 1415.

K. D. Kryter and K. S. Pearsons (1963), "Some Effects of Spectral Content and Duration on Perceived Noise Level", NASA, TN D-18-B.

K. D. Kryter (1966), "Review of Research and Methods of Measuring the Loudness and Noisiness of Complex Sounds", NASA, N66-21098, April 1966.

J. P. A. Lochner and J. F. Burger (1961), "Form of the Loudness Function in the Presence of Masking Noise", J. Acoust. Soc. Am., 33, 1705.

J. E. Parnell, D. C. Nagel and H. J. Parry (1967), "Growth of Noisiness for Tones and Bands of Noise at Different Frequencies", FAA Technical Report DS-67-__.

K. S. Pearsons (1966), "The Effects of Duration and Background Noise Level on Perceived Noisiness", FAA Technical Report ADS-78.

D. W. Robinson (1964), "A Note on the Subjective Evaluation of Noise", J. Sound and Vibration, 1, 468.

D. W. Robinson and L. S. Whittle (1964), "The Loudness of Octave-Bands of Noise", Acustica, 14, 24.

D. W. Robinson, L. S. Whittle and R. M. Bowsher (1961), "The Loudness of Diffuse Sound Fields", Acustica, 11, 397.

S. S. Stevens (1955), "The Measurement of Loudness", J. Acoust. Soc. Am., 27, 815.

REFERENCES (Concluded)

S. S. Stevens (1956), "Calculation of the Loudness of Complex Noise", _J. Acoust. Soc. Am._, 28, 807.

S. S. Stevens (1959[a]), "On the Validity of the Loudness Scale", _J. Acoust. Soc. Am._, 31, 995.

S. S. Stevens (1959[b]), "Cross-Modality Validation of Subjective Scales for Loudness, Vibration, and Electric Shock", _J. Experimental Psychology_, 57, 201.

S. S. Stevens (1959[c]), "Tactile Vibration: Dynamics of Sensory Intensity", _J. Experimental Psychology_, 57, 210.

G. S. Reynolds and S. S. Stevens (1960), "Binaural Summation of Loudness", _J. Acoust. Soc. Am._, 32, 1337.

R. T. Verillo (1962), "Investigation of Some Parameters of the Cutaneous Threshold for Vibration", _J. Acoust. Soc. Am._, 34, 1962.

R. T. Verillo (1963), "Effect of Contactor Area on the Vibrotactile Threshold", _J. Acoust. Soc. Am._, 35, 1962.

APPENDIX I

INSTRUMENTATION

INSTRUMENTATION

1. Magnitude Estimation for Vibration

A block diagram of the test equipment is shown in Fig.
A-1. The Krohn-Hite Model 2024-R variable oscillator was
adjusted for a fixed 0.7 volt, 100 Hz output signal which
was then sent. by means of a "T" connection, to a Daven Type
T-693-R attenuator and a 100 K potentiometer. The potentio-
meter was adjusted for a fixed signal level while the Daven
attenuator could be adjusted for a variable signal level by
the experimenter. The potentiometer and attenuator output
provided two input channels to the BBN electronic gate and
Grason-Stadler electronic switch combination which performed
switching and rise-decay shaping operations for the two
stimuli. The timing of the switching operation was controlled
by an Ampex Model AG-350 tape recorder and polar relay system.
The single-channel output of the electronic switch (consisting
of the alternating standard and comparison signals, each of
four seconds duration and separated in time by 1/2 second)
was delivered to a Ling Model V-47 vibration generator via a
Stromberg-Carlson 150-watt power amplifier. The resulting
motion of the vibration generator spindle, with the attached
finger contactor, was monitored by a Gulton Model A321
accelerometer (sensitivity, 7.8 mv/g). The output of the
accelerometer was passed through a Bruel and Kjaer Type 2630
cathode follower to a Bruel and Kjaer Type 2203 sound level
meter which was used as a millivoltmeter.

The background noise in the test room was produced by
amplifying and reproducing acoustically the "shaped" output
of an Allison Labs random noise generator with a JBL Model
SE 400S 40-watt amplifier and Heathkit Model AS-2 acoustic
suspension speaker system. The shaping of the pink noise
output of the random noise generator was accomplished by
passing the electrical random noise signal through the
Bruel and Kjaer Type 2603 microphone amplifier, Type 1612
one-third octave band filter, and Type 1612 spectrum shaper,
a system which allows each one-third octave band level, in
the audio range, to be adjusted independently.

Acoustic noise levels in the test room were monitored with
a Bruel and Kjaer Type 4133 1/2" condenser microphone and
Type 2203 sound level meter with Type 1613 octave band filter
set. Calibrations of sound pressure levels in the room were
made using a Bruel and Kjaer Type 4220 pistonphone.

A-1
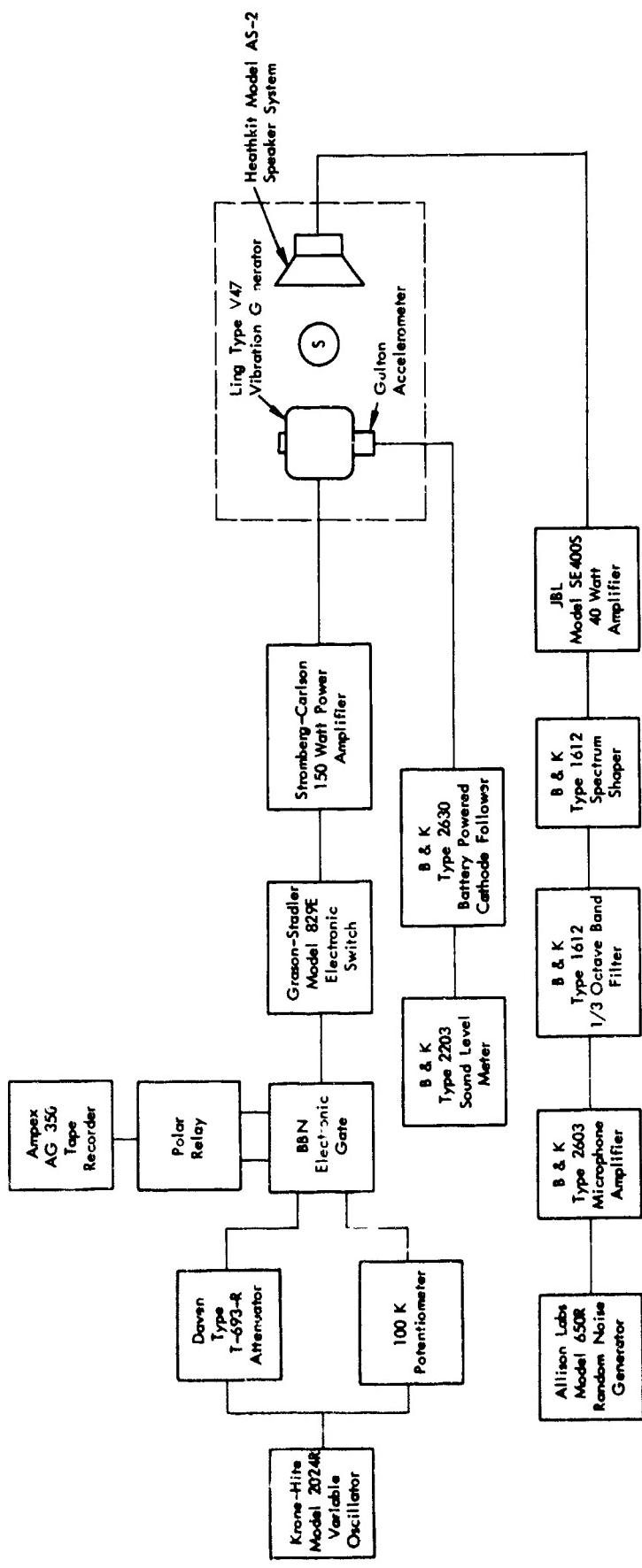
FIGURE A-1. BLOCK DIAGRAM OF EQUIPMENT USED IN MAGNITUDE ESTIMATION OF VIBRATION SENSATION TESTS

In order to reduce the acoustic energy radiated from the vibration generator, it was enclosed in a steel box, which was then filled with lead shot. This essentially isolated the vibrator so that the only noise source was the surface of the finger contactor which protruded through a 7/16" hole in the top of the enclosure.

The dynamics of tactile stimulation have been investigated thoroughly be Verillo (1962, 1963). He concluded that the adequate stimulus for cutaneous sensitivity is displacement (amplitude), although acceleration has also been suggested as being the adequate stimulus.* There appeared to be rather complex relationships between parameters such as shape of the contactor and area of the free space surrounding the contactor. As a function of area, however, the results are fairly well ordered with a 1.5 dB decrease in threshold for every doubling of contactor area. The minimum threshold was found to occur at approximately 250 Hz.

For purposes of our testing however, the vibrator was operated at a frequency of 100 Hz which tended to minimize the audible noise produced by movement of the contactor. With the subject's finger in place on the contactor, sound was audible in a quiet room only at very high operating amplitudes (greater than 50 dB re threshold). The contactor was a round, flat steel button, 1/4 inch in diameter, which was mounted, by means of a small rigid framework, to the spindle of the vibration generator.

2. Cross-Modality Test

A block diagram of the test equipment is shown in Fig. A-2. A Krohn-Hite Model 2024R variable oscillator, adjusted for a fixed 0.7 volt, 100 Hz output signal, and an Allison Labs Model 650R random noise generator provided two input sources to the Grason-Stadler Model 829E electronic switch, which performed switching and rise-decay time shaping operations for the stimuli. The output of the Allison Labs noise

---

* For purposes of this study, it makes no difference whether acceleration or displacement is the important parameter since for sinusoidal motion at a steady frequency displacement equals acceleration times a constant value.
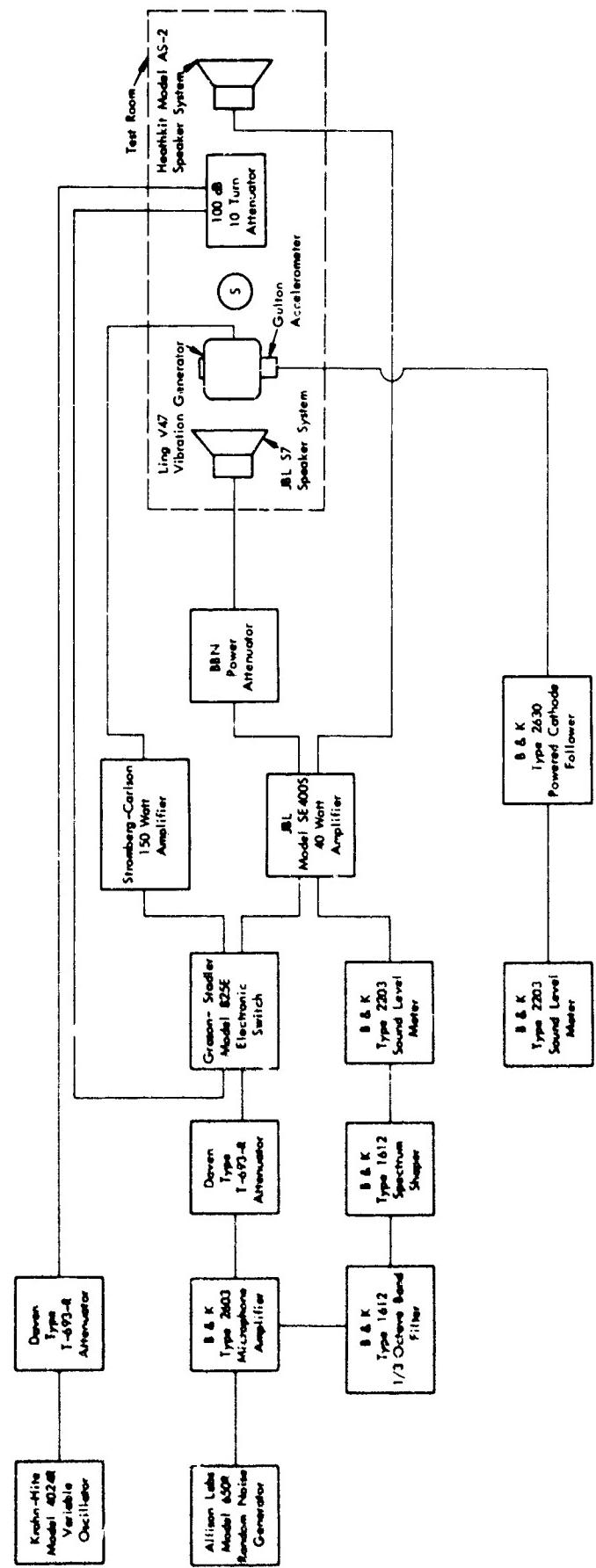
FIGURE A-2. BLOCK DIAGRAM OF EQUIPMENT USED IN CROSS MODALITY TESTS

A-4

generator, a pink noise with equal energy per octave band-
width, was passed through a Bruel and Kjaer Type 2603 micro-
phone amplifier and Type 1612 one-third octave band filter,
with selectable center frequency, before entering the Grason-
Stadler switch. The output of the Krohn-Hite oscillator was
delivered to the switch via a 100 dB, ten-turn Helipot pre-
cision potentiometer, operated by the subject during the
test sessions. The Grason-Stadler switch is a two-channel
output device. Channel 1 output, a discrete frequency, vari-
able level signal, was delivered to the Ling Model V47 vibra-
tion generator via a Stromberg-Carlson 150-watt power amplifier.
The Channel 2 output, a signal of one-third octave bandwidth,
with variable level and center frequency, was delivered to
a JBL Model SE 400S 40-watt solid state amplifier and repro-
duced acoustically through a JBL Model S-7 speaker system.

The background noise in the test room was produced by
shaping the output of the Allison Labs random noise generator
with a Bruel and Kjaer Type 1612 spectrum shaper, allowing
each one-third octave band level, in the audio range, to be
adjusted independently. The shaped signal was delivered to
the second channel of the JBL amplifier via a Bruel and Kjaer
Type 2203 sound level meter, which functioned as a variable
gain A.C. amplifier. The output of the JBL amplifier was
then reproduced through a Heathkit Model AS-2 acoustic sus-
pension speaker system. Both the one-third octave band
signal and the discrete frequency vibration generator signal
were shaped by the Grason-Stadler switch to have four-second
duration and 100 msec rise and decay time characteristics.
The background noise signal was continuous and remained on
throughout a test session.

The acceleration of the Ling vibration generator spindle,
on which the subject finger contactor was attached, was
monitored by a Gulton Model A321 accelerometer (sensitivity,
7.8 mv/g). The output of the accelerometer was passed through
a Bruel and Kjaer Type 2630 cathode follower to a Bruel and
Kjaer Type 2203 sound level meter, used as a millivoltmeter.

Measurement of background noise and one-third octave band
sound pressure levels were made with a Bruel and Kjaer Type
4133 1/2" condenser microphone and Type 2203 precision sound
level meter equipped with a Type 1613 octave band filter set.

APPENDIX II

TEST INSTRUCTIONS

CROSS-MODALITY TEST INSTRUCTIONS

The purpose of these tests is to determine the relative acceptability of various bands of noise.

When the test starts, you will be presented alternately with two stimuli at constant intervals. We will call the noise the standard and the finger vibrator the comparison. The light to your left will indicate the beginning of each trial.

You cannot change the duration of either stimulus but you can change the overall intensity of the finger vibrator by turning the knob on the attenuator that is by your right hand.

Your job is to listen to the standard noise, then feel the finger vibration and then adjust the intensity of the vibrator until it is as acceptable to you as the standard noise. By equally acceptable, we mean that you would just as soon have one as the other in or outside your home periodically 20 to 30 times during the day and night. Stated another way, we mean by equally acceptable that the vibration would be no more nor no less disturbing to you in or outside your home than the standard noise.

It is suggested that, before you proceed to equate the finger vibration to the standard noise, you make the vibration magnitude much more intense than the standard; then make the magnitude much less intense than the standard. With those limits established, adjust the intensity of the finger vibration until it would be just as acceptable as the standard noise in or outside your home. When you have made your decision, press the button in front of you to indicate that you are finished. The sequence will then be repeated. Please use your middle finger which you should rest lightly on the vibrator button at all times.

MAGNITUDE ESTIMATION FOR GROWTH OF
VIBRATION SENSATION INSTRUCTIONS

In this test, you will be asked to judge the relative magnitude of a vibrator which you will feel with your finger. In the beginning of the test you will be presented with a vibratory stimulus. You are to assign a value 10 for the intensity of this stimulus.

You will next be presented with a new stimulus which will be indicated by the light in front of you. You are to assign a value to this new stimulus which is proportional to the relative magnitude of the vibration which you are feeling at your finger. That is, if the vibration feels half as intense as the first stimulus (which has a value of 10), you will assign the number 5; if the vibration feels two times as intense as the first stimulus, you will assign the number 20 and so on. You may use any number that you wish depending upon the intensity of the comparison vibration. Write your estimate on the data sheet in front of you and press the button to indicate that you are finished. The sequence will then be repeated. Please use you middle finger which you should rest lightly on the vibrator button at all times.